Corrosion

Official Publication
NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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HERE IS HOW THIS REMARKABLE PROTECTIVE COATING CAN SAVE YOU MONEY:

1. Only one cross spray coat over a primed surface is required for complete protection—this means lower labor costs.
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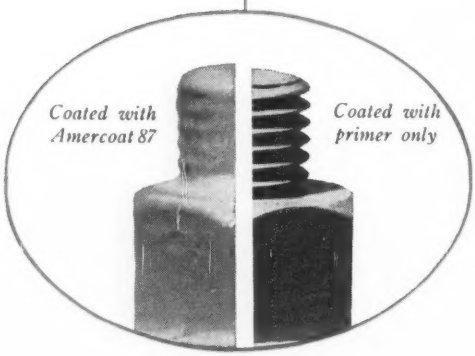

Amercoat 87's thixotropic characteristic helps provide extra thickness on sharp edges and irregular surfaces; it is non-porous and will not crack or check.

Amercoat 87 combines the time-tested chemical and weather resistance of vinyl coatings with the thickness of conventional mastics, yet is easily applied with standard industrial spray equipment.

We will be pleased to send you our technical bulletin describing this coating in detail.

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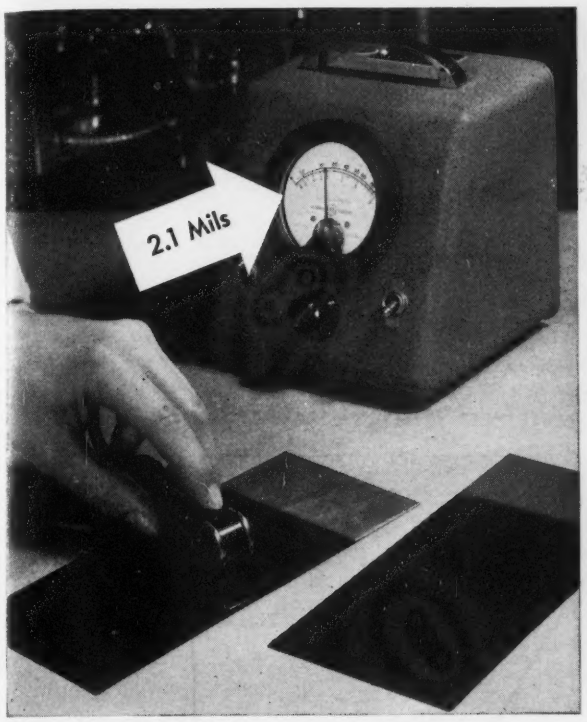


Hot spray. Film-thickness gauge measures single coat of paint sprayed hot. Gauge reads 2.1 mils.

Cold spray. One coat of the same paint sprayed in conventional manner measures only .8 mils.

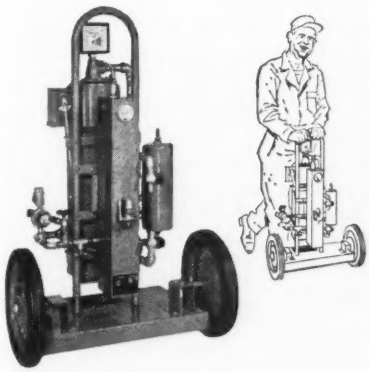
Film-thickness gauge reveals DeVilbiss hot spray puts on more paint per coat!

Each of the steel panels in the test above was sprayed with a *single coat* of black vinyl paint. But the results measured on the film-thickness gauge show one important difference – the paint on the hot-sprayed panel is nearly three times heavier than that on the one sprayed by ordinary methods.

By the controlled application of heat to the spray material, DeVilbiss hot spray gives you heavier film build . . . even with standard formulations.

What's more, materials can be applied efficiently at far lower spraying pressures, greatly reducing spray fog, and resulting in up to 50% savings in material. Finishes dry faster; shrink less; come out glossier. And because fewer passes are needed, operator fatigue is cut way down.

DeVilbiss hot spray is usable on all types of products; can be your means to better finishes at lower costs. For facts on just how much DeVilbiss hot spray can save *you*, call your nearest supplier now! Or write for Bulletin F-286.



Hot spray goes to the job —anywhere—with this new DeVilbiss Portable Paint Heater! Self-contained on easily moved truck, it is complete with automatic controls. Heat-jacketed hose —available in lengths up to 50 feet—keeps paint hot right up to the gun. Write for Bulletin IE-114B.

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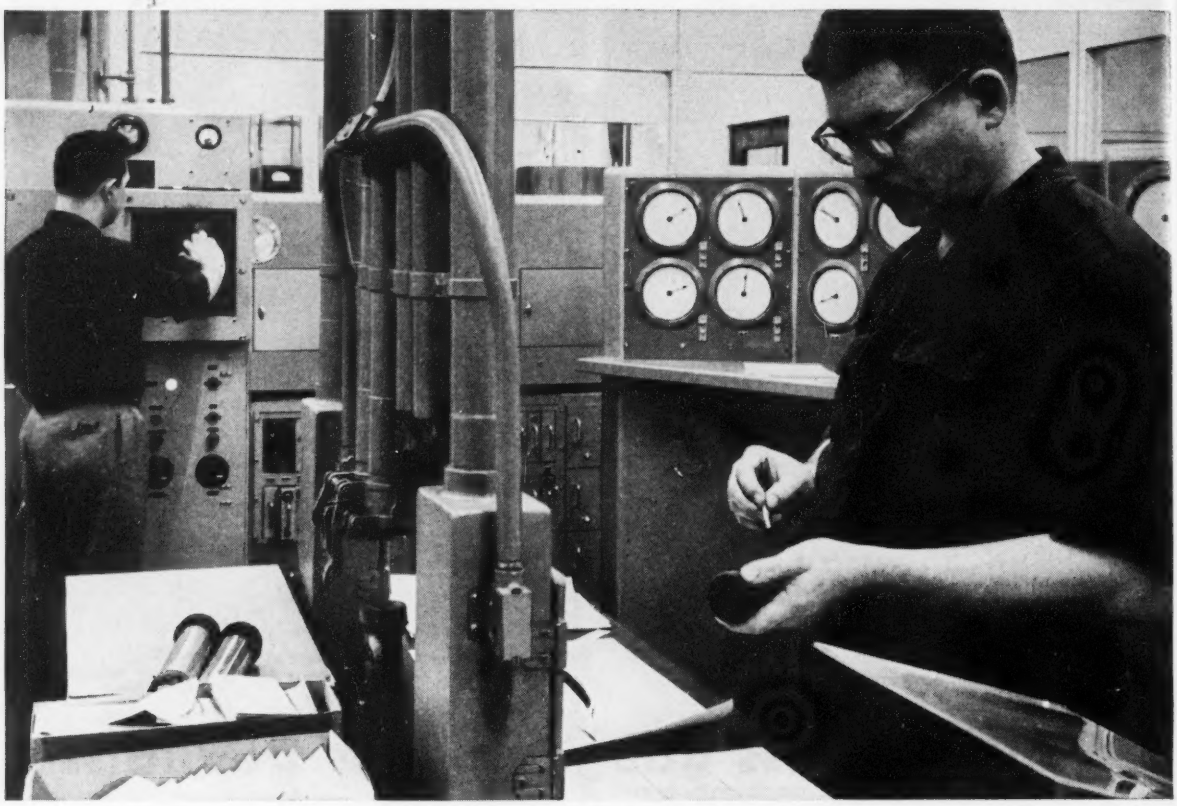

A sample of every melt is rushed to the lab for spectrographic analysis via a pneumatic tube similar to those in department stores.

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CONTENTS

Corrosion

devoted entirely to corrosion research and control

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Vol. 13 February, 1957 No. 2

Page

This Month's Cover ... 4
Directory of NACE Regional and Sectional Officers ... 6, 7, 8
Officers and Directors, NACE ... 16

NACE NEWS

Northeast Region to Meet Oct. 5-8 ... 87
Louisville ASM, Ohio Valley Section to Meet March 1 ... 87
Eastern Wisconsin Section ... 87
Over 200 Attend Detroit Regional Meeting Nov. 15-16 ... 87
Oklahoma City Symposia Chairmen Are Named ... 88
F. A. Prange Elected at Tulsa ... 88
Two NACE Short Courses Scheduled ... 88
NACE Calendar ... 88
Jelen Discusses Economics at AIChE-NACE Session ... 88
Middle East Corrosion Problems Discussed ... 89
Shreveport Section Elects Sullivan ... 89
Cleveland Hears Fontana ... 89
Nominations for 1958 Whitney and Speller Awards ... 90
Toronto Section's Annual Meeting Set Feb. 28-Mar. 1 ... 90
Central Oklahoma Section Elects E. G. Stevens ... 90
Teche Section Names Bassham ... 90
Sprayed Coatings Discussed at Detroit ... 92
Houston Section to Hear W. W. Elley ... 92
National, Regional Meetings and Short Courses ... 92
Cable Sheaths Discussed at Boston ... 92
S. F. Spencer Is Elected ... 92
Illinois University Short Course ... 92
Railroad Corrosion News Letter Issued ... 94
Radioactive Tracers Topic at Los Angeles Meeting ... 94
San Diego Section Elects Officers ... 112

13th Annual Conference and Exhibition News

68-Paper Technical Program Opens Monday, March 11 ... 97
Advance Program Mailed ... 97
Important St. Louis Meeting ... 97
Registration Hours Listed ... 97
Fun, Music and Humor Feature Banquet Entertainment ... 98
Exhibition Hours Set ... 98
Corporate Members Luncheon Scheduled ... 98
General Corrosion Symposium to Hold Two 4-Paper Sessions ... 100
Inhibitor Papers Cover Automobile Engines, Light Alloy Couples ... 108
Two-Paper Corrosion Principles Symposium Is Scheduled ... 110
Rogers and Wagner Will Receive NACE Awards ... 112
Fourteen Exhibitors Added to St. Louis List ... 112

(Continued on Page 4)

TECHNICAL SECTION

Page

Topic of the Month—Embrittlement of 12 Percent Chromium Steel Thermocouple Nozzles on a Thermofor Catalytic Cracking Unit Reactor
By H. Howard Bennett ... 17

Selection of Rust Inhibitors to Meet Service Requirements
By A. J. Freedman, A. Dravnieks, W. B. Hirschmann and R. S. Cheney ... 19

Study of a Size Effect in Galvanic Corrosion
By James T. Waber ... 25

Use of High Silicon Cast Iron for Anodes—First Interim Report of NACE Technical Unit Committee T-2B on Anodes for Impressed Current. Publication 57-4 ... 33

The Use of Graphite As Duct Anodes
By A. L. Ayres ... 38

Bibliographies of Corrosion Products. Section One—A Report by NACE Technical Unit Committee T-3B on Corrosion Products. Publication 57-5 ... 41

An Impressed Current Cathodic Protection System Applied to a Submarine
By E. E. Nelson ... 52

Cathodic Protection of an Active Ship Using A Trailing Platinum-Clad Anode
By H. S. Preiser and F. E. Cook ... 55

Casing Corrosion in the Petroleum Industry
By Jack L. Battle ... 62

Measurement of the Instantaneous Corrosion Rate By Means of Polarization Data
By R. V. Skold and T. E. Larson ... 69

Lead Cable Sheath Corrosion Under Cathodic Protection Conditions
By Walter H. Bruckner and Ray M. Wainwright ... 73

TECHNICAL COMMITTEE ACTIVITIES

70 Technical Committees Meet at St. Louis ... 79

Tentative Committee and Technical Program ... 79

Sweet Oil Well Iron Content Anomaly to Be Investigated ... 79

Inhibitor Screening Method Satisfactory ... 81

Roach Heads Canadian T-7 Coordinating Committee ... 82

Coated Tubing Experience Reported to T-1C ... 82

Magnesium Cased Inhibitors Give Good Results in Salt Water Wells ... 84

Improved Methods Urged for Using Inhibitors ... 84

Corrosion in Pipe Line Oil Wells Reported to T-1C ... 85

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CONTENTS

(Continued From Page 3)

GENERAL NEWS

	Page		Page
Night Credit Course on Corrosion Is Offered	114	Pores in Electroplated Coatings Can Be Located	114
Japanese Electrolysis Committeemen Meet	114	Book News	116
Metals Congress Schedules Corrosion Panel Session	114	Seahorse Institute Sessions	116
Appalachian Underground Course Set for June 5-7	114	Outdoor Storage on Agenda at Materials Handling Meet	116
Parthian Electroplaters Used Primary Cell	114	Magnetic Particle Coating Photographs Published	116
		New Products	118
		Men in the News	120

Index To Corrosion Abstracts 121

Index to Advertisers 143

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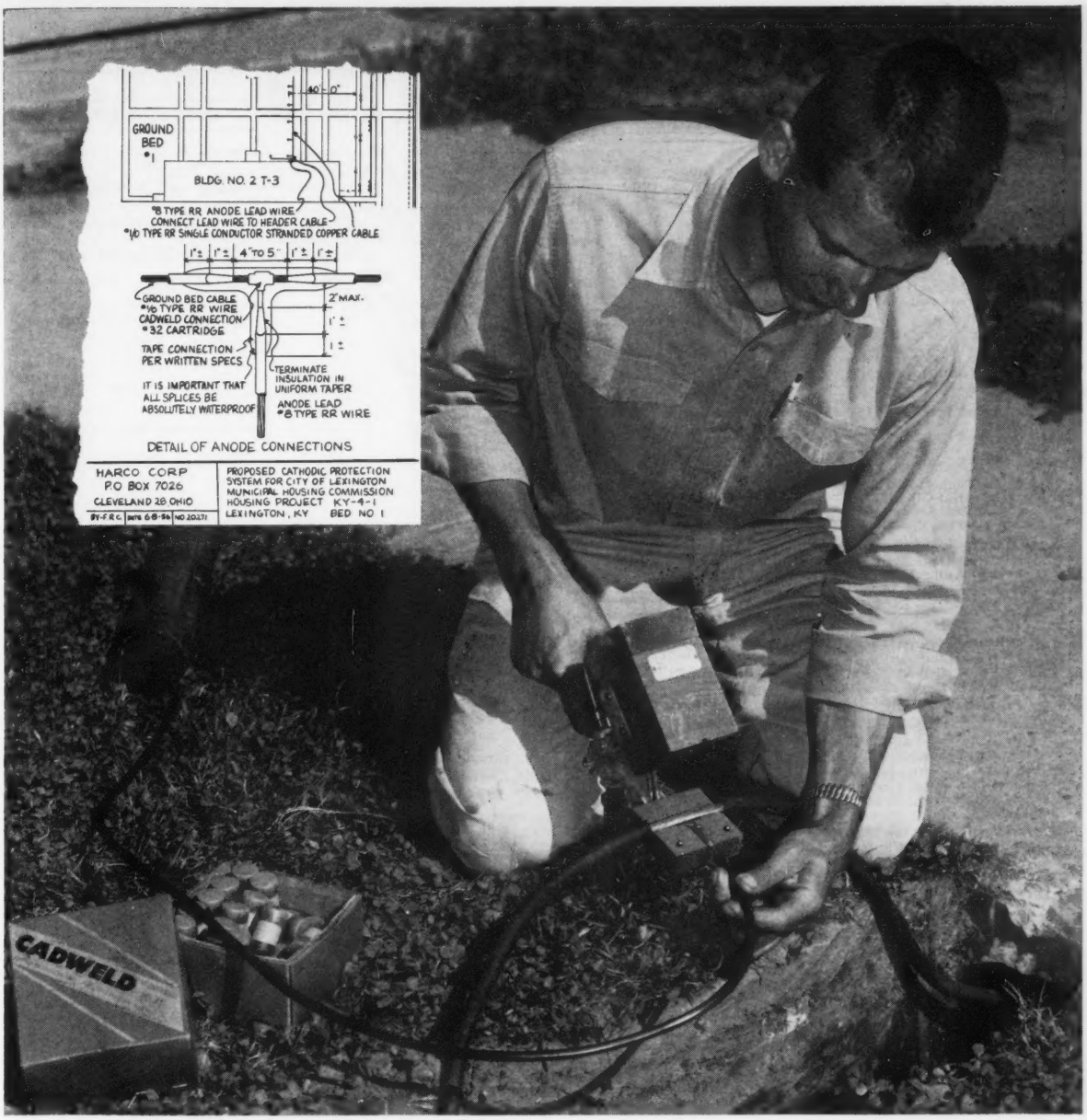
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(Continued on Page 8)

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U.S.I. CHEMICAL NEWS

A Series for Chemists and Executives of the Solvents and Chemical Consuming Industries

Greenleaf to Handle Market Development of Zirconium And Titanium for U.S.I.

William C. Greenleaf has been named Manager of Metals Development for U.S.I. and will be responsible for market development and sales of zirconium and titanium sponge, to be produced from U.S.I.'s two new plants now being built in Ashtabula, Ohio.

A recognized authority in the field of zirconium and titanium, Mr. Greenleaf presented three papers during the 1955 Atomic Industrial Forum Zirconium Program, describing (1) melting of zirconium, (2) fabrication of zirconium, and (3) zirconium mill products and prices. He also conceived and developed processes now in general use for producing both wide-sheet and flat-bar titanium and zirconium by continuous strip-mill techniques.

Faye Named Manager of Sodium Product Sales

Martin Faye has been named Manager of Sodium Product Sales for U.S.I. and will be responsible for coordinating sales and sales promotional activities for metallic sodium, "U.S.I. Isosebacic" acid and related products.

Mr. Faye joined the U.S.I.-National Distillers organization in 1952 in the Market Research and Development Department.

TECHNICAL DEVELOPMENTS

Information about manufacturers of these items may be obtained by writing the Editor, U.S.I. Chemical News.

A zirconium-copper alloy now available is reported to combine high electrical conductivity with good strength retention at elevated temperatures. Suggested for electrical motor commutators serving above 500°F where strength is needed. Conductivity is 95.8% of copper. **No.1193**

Titanium wire cloth is now on the market in sizes from 60 mesh to coarser grades. It is reported to be particularly suitable for filtering or screening highly corrosive materials. **No. 1197**

Zirconium and Titanium Lick Roughest Corrosion Problems

Metals to be Available at Lower Cost in Future; Provide Long-Lived Materials of Construction; Complement Each Other on Corrosion Resistance

It is now practical to fabricate equipment which is *corrosion-resistant to almost every substance encountered in industry*, by using either zirconium or titanium metal. Alloys of either metal, or possibly both, may extend the range even further.

Industrial applications of these metals have been hampered by two considerations: availability and price. Zirconium will shortly be produced at a rate sufficient to supply industrial needs, and titanium has been available to industry during the past two years. And it is expected that increased production of these metals during the next few years will result in significant price decreases.

Twelve to thirteen thousand tons of titanium were available in 1956 and present construction schedules indicate that the figure will rise substantially in 1957. U.S.I.'s new plant alone will add 5,000 tons to the annual production capacity by the end of the year. Zirconium will be on the market in quantity by mid-1957. When its new plant at Ashtabula, Ohio gets under way, U.S.I. will be able to supply 500,000 pounds or more per year to commercial users in addition to its Atomic Energy Commission commitments of 1,000,000 pounds per year.

New Metals Economical

Chemical process equipment can now be fabricated from titanium for a little over twice the price of stainless steel, and it is expected that in the future titanium equipment will be only 50-75% higher than stainless. Commercial grade zirconium equipment will probably be priced only 75-100% higher than stainless when volume production is reached.

Typical Corrosion Resistances* of Zirconium and Titanium

Corrosive Media	Metal Resistance	
	Zirconium	Titanium
Sulfuric Acid	excellent to good below 80%	good below 5%
Nitric Acid	excellent	excellent
Hydrochloric Acid	excellent	good below 10%
Phosphoric Acid	excellent to fair below 85%	poor
Chromic Acid	excellent	excellent to good
Aqua Regia	poor	excellent
Wet Chlorine Gas	poor	excellent
Chlorine Water	excellent	excellent
Sodium Hydroxide	good below 90%	good below 50%
Ferric Chloride	poor	excellent
Calcium Chloride	excellent	excellent
Cupric Chloride	poor	excellent
Sodium Chloride	excellent	excellent
Ammonium Chloride	excellent	excellent
Aluminum Chloride	excellent	excellent to fair

*Above data do not cover all conditions because of space limitations. Literature references may be obtained by writing the Editor, U.S.I. Chemical News, 99 Park Ave., N. Y. 16, N. Y.

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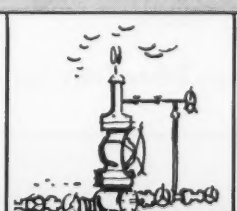

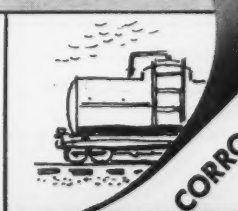

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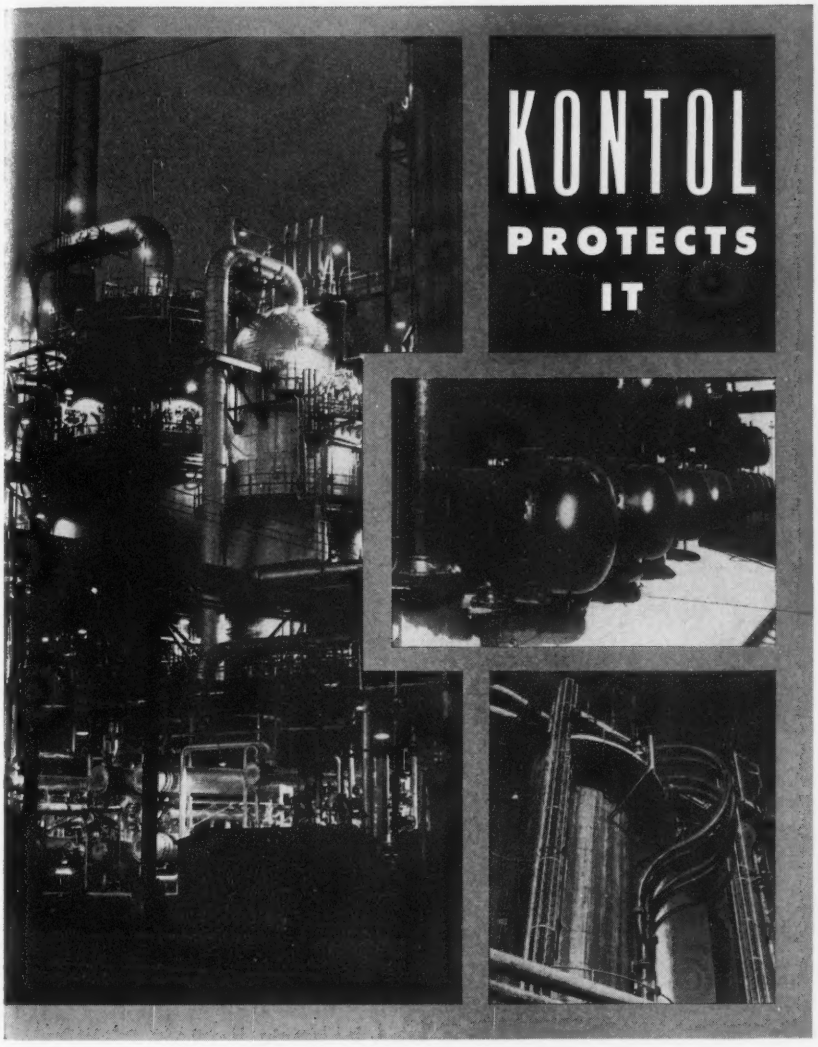

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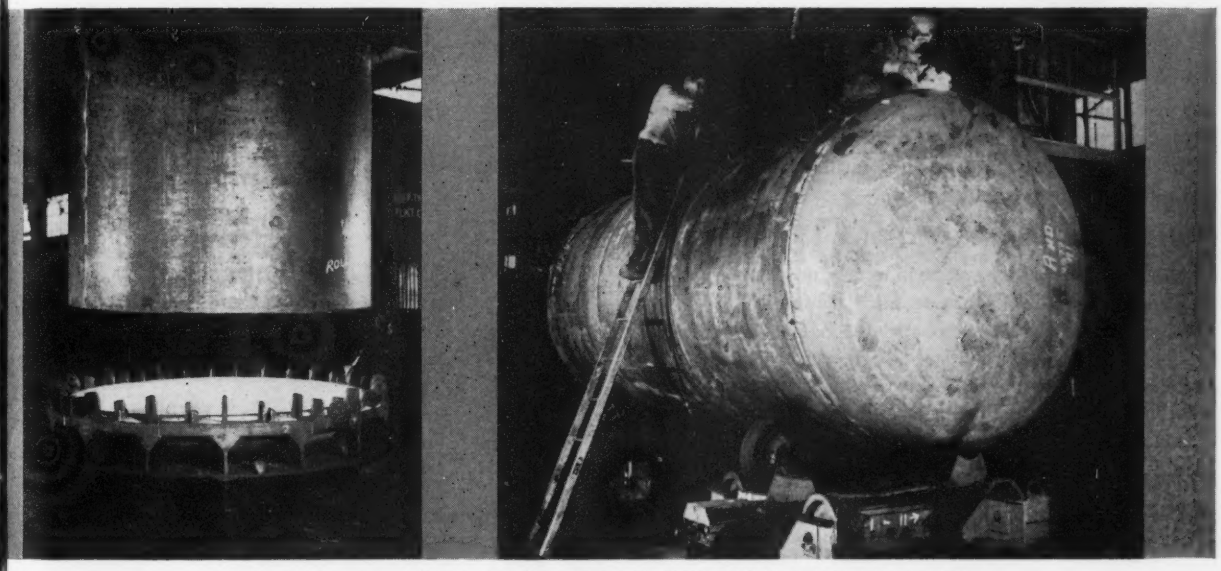

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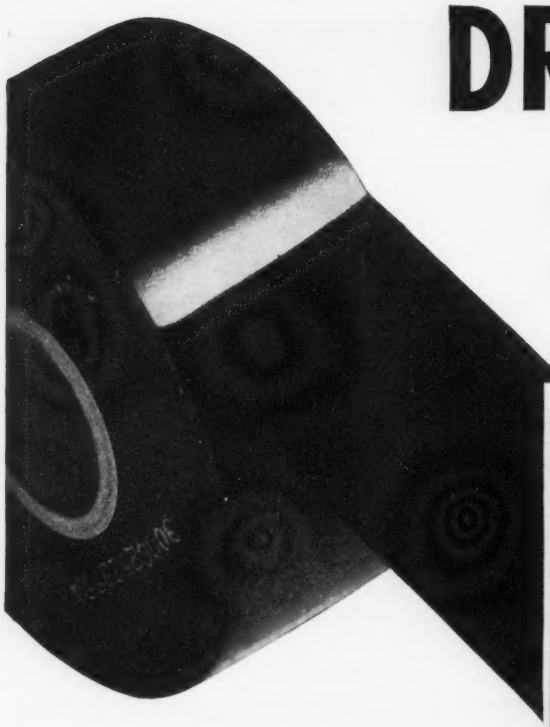

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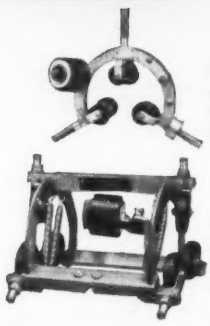

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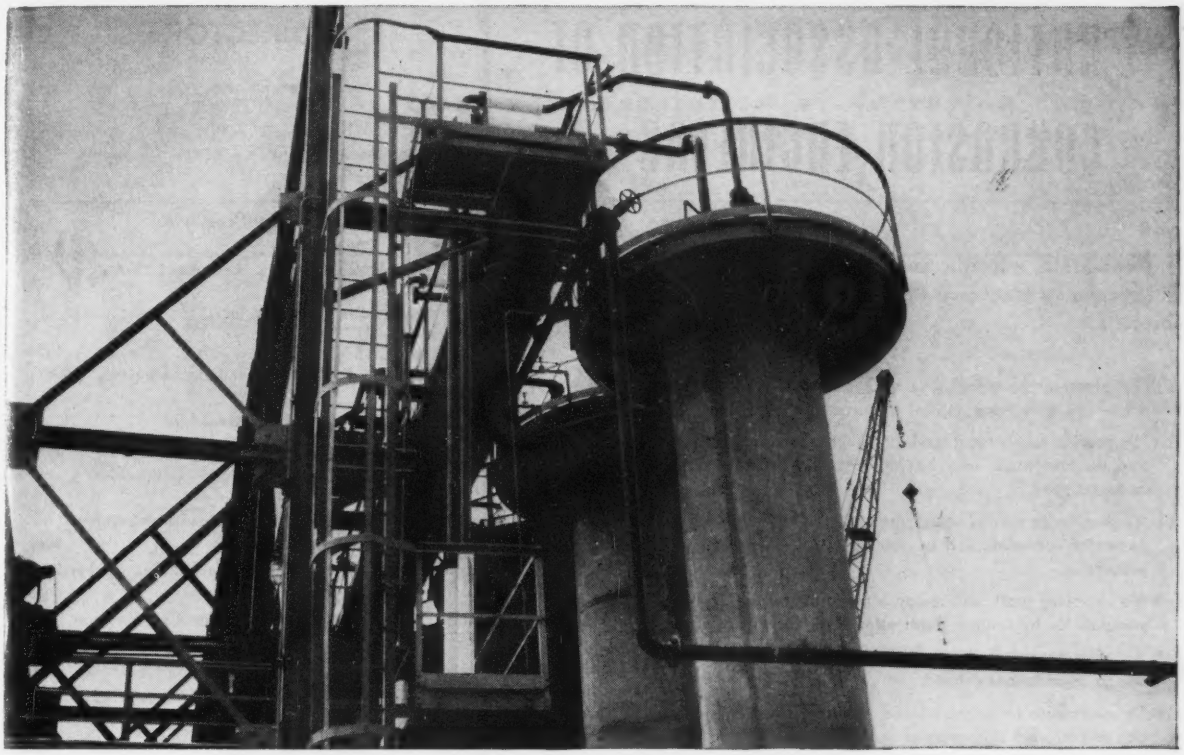

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Corrosion

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Topic of the Month

Embrittlement of 12 Percent Chromium Steel Thermocouple Nozzles on a Thermofor Catalytic Cracking Unit Reactor

By H. HOWARD BENNETT*

Introduction

DURING A RECENT turn-around of a Thermofor catalytic cracking unit, several nozzles on the reactor fractured during the removal of the thermocouple wells. A slight build-up of coke between the thermocouple well and the nozzle hindered easy removal of the wells. When force was applied to the thermocouple well to free it, the nozzle fractured at the point shown in Figure 1. The 2⅜-inch outside diameter, ¾-inch wall nozzles were of a 11-13 percent chromium alloy of a composition similar to the reactor cladding.

The appearance of the nozzle at the point of fracture is shown in Figure 2. The metal in the nozzle at the point of failure had been subjected to a temperature of from 850 to 1,000 F for approximately 100,000 hours. These temperatures embrace the 885 F temperature at which embrittlement has been reported[1] in ferritic stainless steels with a chromium content as low as 12 percent. Since maximum hardness has been reported as occurring at this temperature, hardness determinations were made on the metal near the point of failure and values of 99 to 103 Rockwell B were obtained. However, hardness measurements taken at a cooler location 4 inches away from the failure ranged from 82 to 83 Rockwell B.

Grain Boundary Precipitates

Figure 3 is a photomicrograph of the metal adjacent to the fracture which clearly shows widening of the grain boundaries. This condition was reported by Riedrich and Loib,[3] who concluded that the embrittlement was caused by the grain boundary precipitates. These precipitates are suspected of being

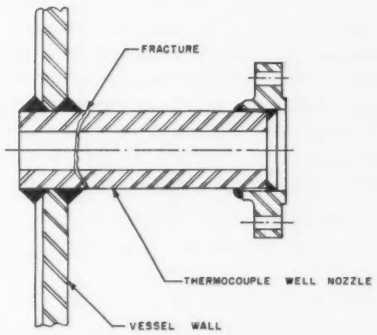

Figure 1—Location of nozzle fracture.

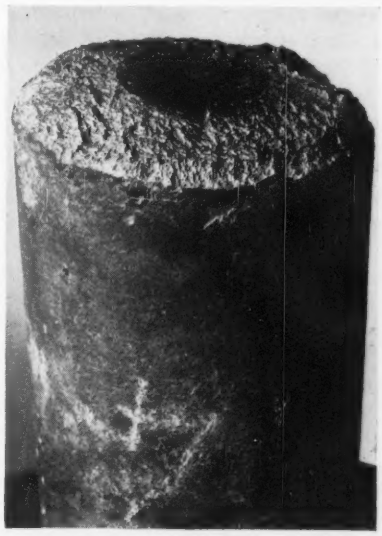

Figure 2—Fractured surface of nozzle.

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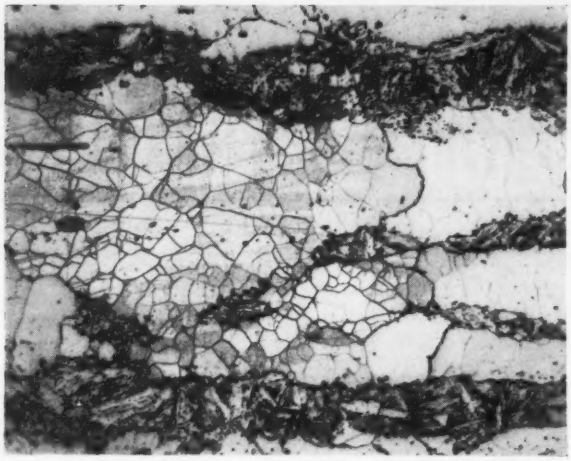

Figure 3—Structure of metal adjacent to fracture. Marbles reagent, 380X (made from a photograph taken at an original magnification of 500X).

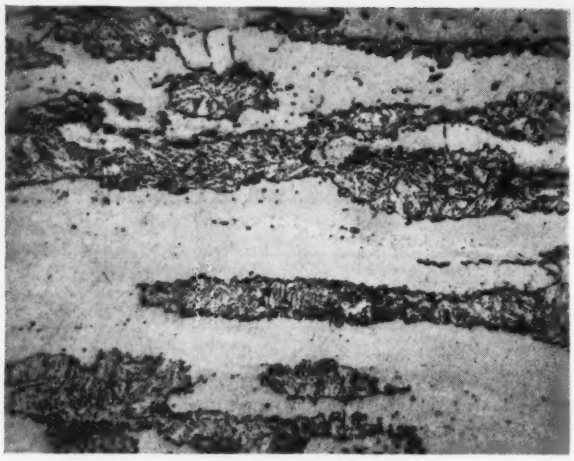

Figure 4—Structure of metal four inches from fracture. Marbles reagent, 380X (made from a photograph taken at an original magnification of 500X).

carbides, sigma phase formation, or possibly nitrides and phosphides. Since embrittlement occurs in a pure iron chromium alloy, several investigators[4] believe that sigma phase is most likely responsible for the embrittlement.

Figure 4 is a photomicrograph of the metal 4 inches away from the failure where the temperature was lower. It will be noted that the microstructure of the metal shows no widening of the grain boundaries.

It is believed that this failure confirms the observation by Krivobok that much prolonged time of heating would extend the limits of compound (sigma phase) formation far beyond those sketched at the present time and that the higher chromium steels in long time service should be looked upon with suspicion.

Acknowledgment

The author is indebted to J. E. Prior of Socony Mobil's Research and Development Laboratory for the metallographic examination.

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Selection of Rust Inhibitors To Meet Service Requirements*

By A. J. FREEDMAN, A. DRAVNIEKS, W. B. HIRSCHMANN and R. S. CHENEY

Abstract

Rust inhibitors should be selected with reference to the type of service in which they will be used. Many inhibitors which give satisfactory results under mild rusting conditions fail to provide useful protection under more severe conditions. Laboratory testing programs should be designed, therefore, to reproduce as closely as possible the conditions of actual practice.

Rust inhibitor test methods are discussed in relation to three general classes of service, corresponding to flowing, static, and condensation conditions. A new rust inhibitor testing procedure, based on the Indiana Conductometric Test, provides quantitative measurements of very low corrosion rates under carefully controlled conditions. Small differences in the performance of good rust inhibitors have been detected by this method.

The choice of general type of rust inhibitor (aqueous- or oil-soluble) as well as the particular compound to be used in any case, should be based on the results of selected quantitative laboratory tests, correlation with field tests and experience, and an analysis of relative cost data for useful inhibitors on an equal protection basis. An economic evaluation of possible alternate procedures for obtaining any desired degree of rust protection also should be made.

5.8.1.

Introduction

DURING THE past several years, a wide variety of rust inhibitors have appeared on the market. It has been claimed that these inhibitors protect refinery equipment, tanks, trucks, and pipe lines from rusting caused by water, and prevent contamination of products with rust. Laboratory tests indicate, however, that most of these inhibitors are somewhat less than perfect. That is, although all of these inhibitors are at least partially effective, no one compound yet tested has given ideal rust protection under all types of operating conditions.

Rust inhibitors belong to several different chemical classifications, such as amines and amine salts of organic acids, and it is to be expected that the behavior of these materials should depend upon the conditions to which they are exposed. The problem of selecting a rust inhibitor for a particular application is, therefore, quite complex. First it is necessary to define the conditions under which the inhibitor must perform, and the level of protection which is required. In general, contamination of products with rust is of more concern than the decrease in life of metal equipment in products service. Hence, for each application, it is necessary to determine whether or not the cost of a rust inhibitor program can be justified. Such a justification usually involves an economic analysis of the benefits which may be expected from the use of the inhibitor, plus an analysis of alternate ways of solving the problem. And finally, by means of a suitable laboratory and field evaluation program, the inhibitor must be selected which will give the required protection at the lowest possible cost.

Laboratory Rusting Tests

The problem of defining the service conditions under which an inhibitor is expected to give protection is of the utmost importance. It certainly is true that the behavior of any inhibitor in a particular application can be measured exactly only by a field trial under actual service conditions. However, for any sort of comprehensive testing program involving a number of inhibitors, field trials are prohibitively expensive and time-consuming. Hence, some sort of accelerated laboratory tests must be devised which will permit the evaluation of inhibitors on a relative basis, under conditions approximating those in the field. Inhibitors which show promise in the laboratory tests then can be examined under plant conditions.

Since it is not practical to devise a specific laboratory test corresponding to each application for which an inhibitor is desired, three general classes of service have been established, representing, respectively, dynamic, static, and condensation conditions. Tests have been devised which correspond to each of these cases.

Dynamic tests correspond to situations involving flowing streams such as are found in pipe lines. Static tests are intended to represent more severe rusting conditions such as occur in storage tanks and other equipment in which metal contacts static liquids for extended periods of time. Finally, condensation tests represent those very severe conditions which occur in open vessels and other equipment exposed to moisture condensed from the atmosphere.

A number of well-known rusting tests, such as the ASTM Turbine Oil Test[1] and the Navy Static Drop Test,[2] are used throughout the industry for inhibitor evaluation studies. The ASTM Test corresponds to dynamic conditions and the Navy Test to static conditions. In order to represent condensation conditions, a modification of the standard Navy Test has been developed. For this purpose, the familiar triangular specimen, containing a small dimple, is first soaked in inhibited gasoline and then placed in an empty beaker before the drop of water is placed in the dimple. Under these severe conditions, no new inhibitor is available for repair of inhibitor films which are destroyed by rusting, and an extremely

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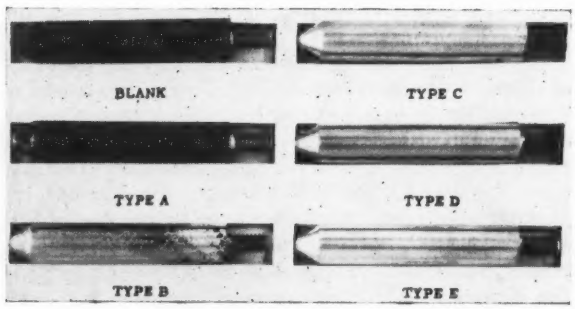

Figure 1—Comparison of rust inhibitors at two pounds per 1000 barrels (ASTM Method).

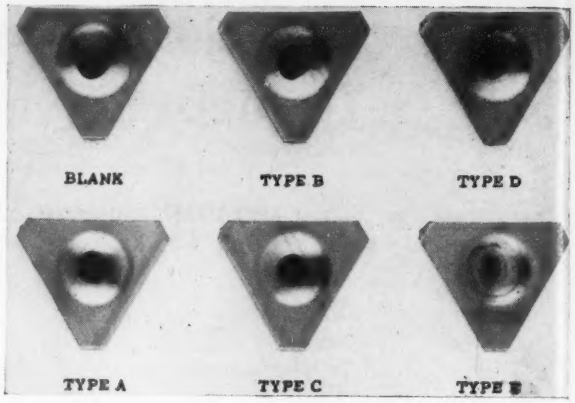

Figure 2—Comparison of rust inhibitors at five pounds per 1000 barrels (Navy Static Drop Test).

stable film is required to prevent further corrosion. Although some of the best rust inhibitors give partial protection in this test, no compound yet examined has prevented rusting completely under these conditions.

To illustrate the effect which test conditions can have on the performance of some different types of rust inhibitors, Figure 1 shows some dynamic ASTM test specimens prepared at inhibitor concentrations of 2 pounds per 1000 barrels. Deionized water was used in these tests. Note that Type A inhibitor gives little or no protection under these conditions, Type B gives partial protection and Types C, D, and E inhibitors completely prevent rusting.

Figure 2 illustrates the performance of these same inhibitor types in the conventional Navy Static Drop Test. Under these more severe conditions, inhibitor Types A, B, and C fail completely, Type D yields fair results, and Type E gives almost complete protection. Thus, for example, Type C inhibitor might be a good choice for an application involving mostly flowing conditions, but laboratory data indicate that it will be less effective than Types D and E in storage tanks and other static situations.

All of these well-known rusting tests have one fault in common. This shortcoming is that the measurement is qualitative, or at best semi-quantitative, and depends entirely upon the visual comparison of a rusted specimen with a blank. Such methods are quite suitable for separating good inhibitors from weak ones. However, reliable estimates of the relative effectiveness of two good inhibitors are difficult or impossible to secure by these methods, both because the methods lack sensitivity and because the human errors involved in visual estimates of rusting are both large and variable.

What is required is a highly sensitive and reproducible accelerated corrosion test from which quantitative measurements of corrosion rates can be obtained under a variety of conditions. The usual coupon measurements, of course, will yield quantitative rusting data, but in many cases long periods of time are required to get sufficient sensitivity and reproducibility.

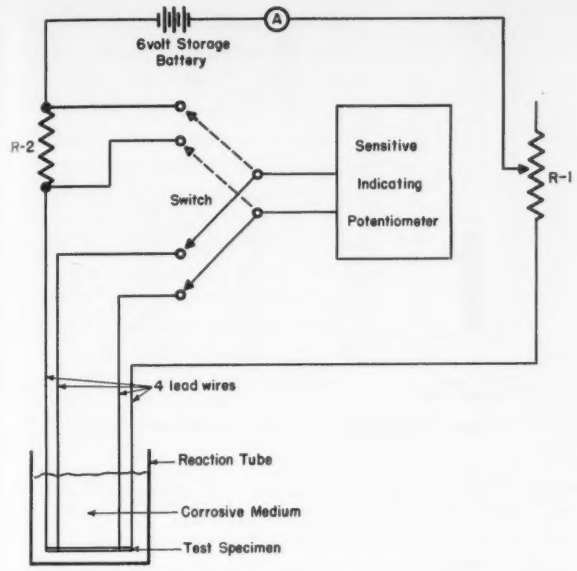

Figure 3—One type of electrical circuit developed for conductometric rusting tests.

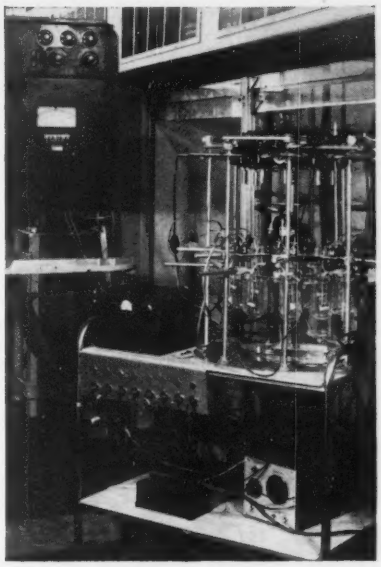

Figure 5—Photograph of multiple testing apparatus (conductometric method).

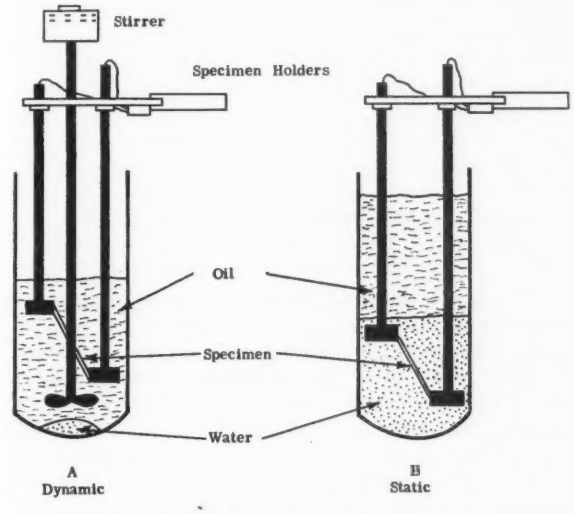

Figure 4—Apparatus for conductometric tests.

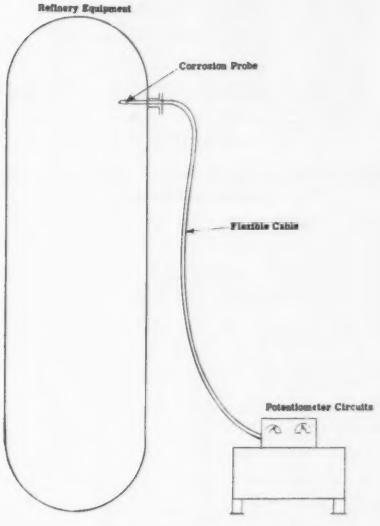

Figure 6—Corrosion probe field installation.

The Indiana Conductometric Rusting Test

There has been developed a quantitative rusting test based on a conductometric method of measuring corrosion rates. The basic features of this method, which involve the measurement of the change in electrical resistance of a metal strip immersed in a corrosive medium, were described by A. Dravnieks and H. A. Cataldi at the annual NACE meeting in 1954.[3,4] Since that time, the high sensitivity, accuracy, and reproducibility of this method have become increasingly recognized throughout the industry.[5,6,7]

Figure 3 is a schematic diagram of an electrical circuit used in the present work for corrosion testing by the conductometric method. Contacts are made with two lead wires to each end of a thin metal ribbon, usually 1 or 2 mils thick. Current from a 6-volt storage battery is passed through the specimen, a variable load resistor R-1, and a standard Manganin resistor R-2. A sensitive indicating potentiometer is connected to measure the potential drop across R-2 and the specimen, in turn. The specimen is placed in the corrosive medium and thermostatted at 100 ± 0.5 F. With the potentiometer connected across R-2, R-1 is adjusted so that a constant current of about 0.5 ampere, as indicated by the ammeter and measured accurately by the potentiometer, flows through the circuit. The potentiometer then is connected across the specimen and the potential drop is recorded. This procedure is repeated several times during the experiment. From the change in resistance of

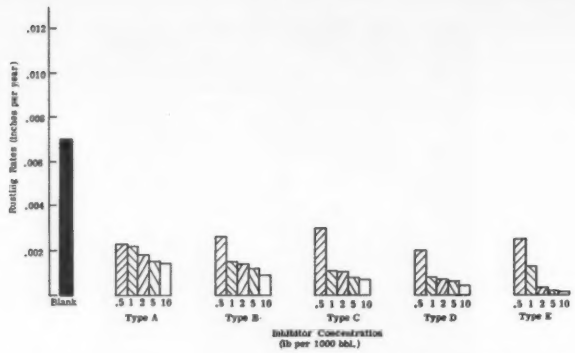

Figure 7—Effect of concentration on rust inhibitor performance (dynamic conductometric test).

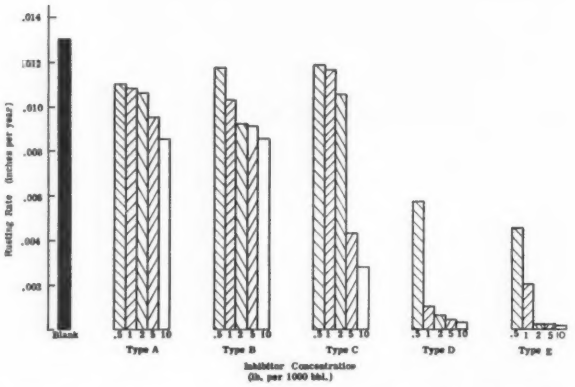

Figure 8—Effect of concentration on rust inhibitor performance (static conductometric test).

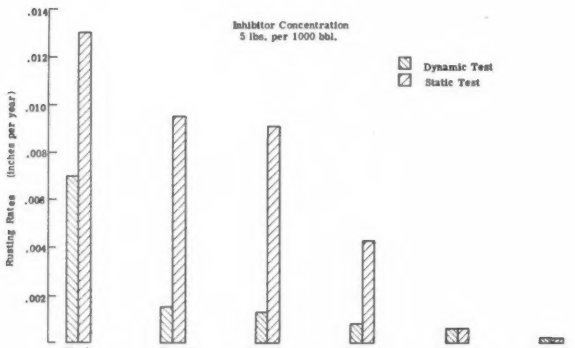

Figure 9—Comparison of rust inhibitors by conductometric method.

the specimen with time it is a simple matter to calculate the corrosion which has occurred. Usually a multiple switching arrangement is used so that as many as 16 specimens can be measured during one experiment.

Figure 4 shows schematically the apparatus which was used in the present work for rust inhibitor testing by the conductometric method, under both static and dynamic conditions. Each specimen holder is adapted to support two specimens in specially designed clamping plates which include electrical con-

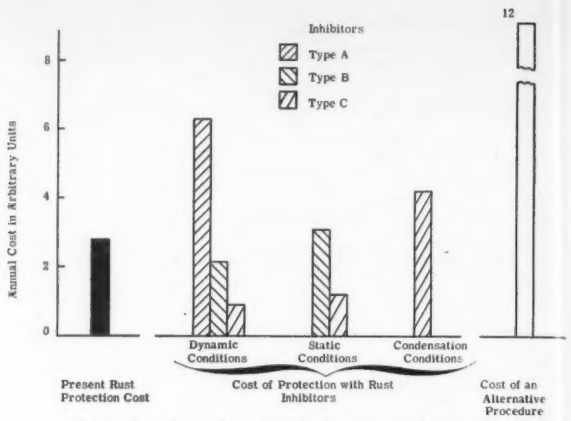

Figure 10—Analysis of typical rust protection costs.

tacts. The lead wires to these contacts pass through the base of the specimen holder. The test specimens can be prepared from any of the common metals. As is the case with any laboratory corrosion test, variations in surface properties can have large effects on the measured corrosion rates. In the case of carbon steel specimens, a thorough cleaning with carbon tetrachloride and acetone, followed by vacuum annealing for one hour at 1200 F and less than one micron total pressure, has been found to be a satisfactory method for preparing a uniformly sensitive surface. The annealed specimens should be stored in vacuum until used.

For dynamic tests in the laboratory using the Indiana Conductometric Test, a mixture of rust-inhibited oil plus 1 percent deionized water is placed in the tube with the specimens, and the mixture is stirred rapidly for 24 hours. Potential measurements are made at frequent intervals during this period.

For testing under static conditions, approximately equal volumes of oil and water are used, and the mixture is stirred briefly before the specimen holder is placed in the tube. This stirring serves to distribute the inhibitor at equilibrium concentrations in both phases. After the two phases have separated, the specimens are suspended in the oil phase for one hour to permit them to adsorb inhibitor, and then are lowered into the water phase where potential measurements are made as before.

Figure 5 is a photograph of a multiple-testing apparatus. The picture shows the specimen holders mounted in a constant temperature water bath, the stirring motors, the control box for switching the current and potentiometer from one specimen to another, and the indicating potentiometer.

The conductometric method also can be applied to field testing in refinery equipment. For this purpose, a corrosion probe has been designed for inserting a conductometric specimen through a thermo-well or similar opening in a unit.

Figure 6 shows schematically how such a probe would be used in connection with a refinery vessel. Measurements may be taken manually, or the circuit may be designed for use with a recording potentiometer.

Conductometric Test Results

Some typical laboratory results obtained with the Indiana Conductometric Test under dynamic conditions are shown in Figure 7. Data are presented for five different inhibitors and a blank, at concentrations ranging from 0.5 to 10 pounds per 1000 barrels. The rusting rates calculated from the resistance changes are shown extrapolated to inches per year in order to use familiar units. It must be remembered, however, that these are accelerated laboratory test data, and actual rusting rates determined in the field may be considerably different. However, the relative rates shown in this chart still are valid for comparative purposes.

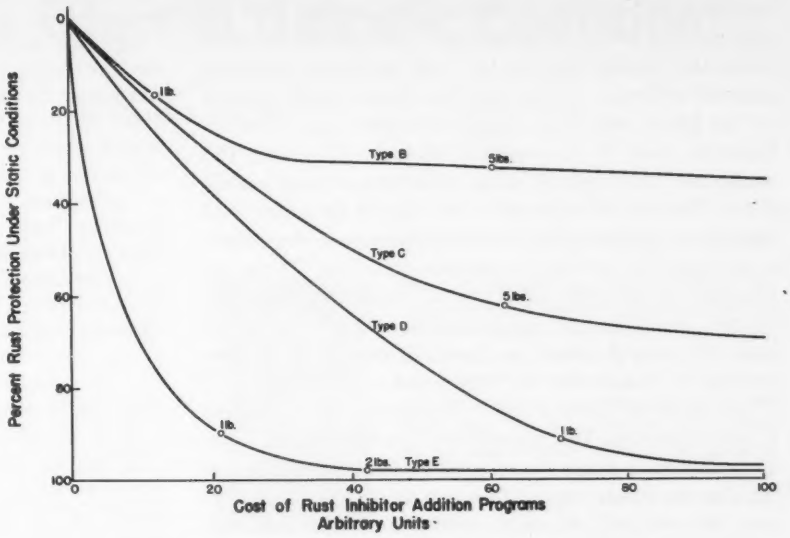

Figure 11—Annual cost of rust protection with various inhibitors.

Each bar on the chart represents an average of many determinations, and the data are considered to be reproducible within two percent. The differences between inhibitor types, and the effects of concentration shown on this chart, could not be detected by purely visual means; most of these compounds, for example, give perfect protection in the ASTM test at 2 pounds per 1000 barrels. It is clear that under dynamic conditions, these types of inhibitors are effective at concentrations as low as 1 or 2 pounds per 1000 barrels. Also, although Type E, for example, is obviously more effective than Type A, the differences are not large and even the weaker inhibitors may be expected to yield satisfactory rust protection under these relatively mild conditions.

Figure 8 presents comparable data for the same types of inhibitors taken under more severe static conditions. The differences are striking. Whereas under dynamic conditions the differences between Types C and D, for instance, probably are not significant, under static conditions these differences are quite important. Also, when evaluating these static data on an economic basis, it is important to observe that Type D inhibitor is effective at concentrations as low as 1 or 2 pounds per 1000 barrels, whereas at least 5 pounds of Type C per 1000 barrels is required to give significant protection.

Figure 9 compares directly the Indiana Conductometric Test results under static and dynamic conditions. All data shown in this graph were obtained at the 5 pounds per 1000 barrel level. The graph shows clearly the much lower rusting rates that occur under dynamic conditions, and the much smaller percentage differences between inhibitors.

Economic Analysis

Both the beginning and the end of any inhibitor testing program is the economic problem. Once the test conditions appropriate to a particular problem have been selected and some experimental data have been obtained, an economic analysis based on these data is required to determine whether or not rust inhibitors represent a feasible solution to the problem.

One way to carry out this analysis is illustrated in Figure 10. This graph compares some of the costs involved in a typical rusting problem. The black bar on the left represents present costs of rust protection in this situation. These costs include such items as pipe line cleaning, dehydrators, and meter maintenance. It is presumed that this present level of protection is inadequate, and that improvement is desired. Laboratory experiments indicate that a satisfactory level of rust protection under flowing conditions can be obtained with any of three types of rust inhibitors, A, B, or C, although not necessarily at equal concentrations. The graph then shows that this protection can be obtained at least cost with Type C. This represents a considerable savings over present operations. Type A is much more costly on this equal protection basis, and should not be considered. Alternatively, a higher level of rust protection, satisfactory under both flowing and static storage conditions, can be obtained at somewhat higher costs with either inhibitor Types B or C, but not with Type A. Finally, satisfactory protection under the most severe condensation conditions can be obtained only with Type C, and at a substantially increased cost which actually is higher than present costs.

Other means of solving the corrosion problem also must be considered, such as filtration of products to eliminate contamination with rust. The graph shows in this case that the cost of one possible alternative procedure would be prohibitive compared to present costs or to the cost of inhibitors.

Once it is established that rust inhibitors represent the best solution to a particular problem, and after good quantitative rusting data are obtained under laboratory conditions as close to actual service as possible, these data then must be analyzed on an economic basis in order to select the most promising compounds for field trials.

Figure 11 shows one method of analyzing rust

inhibitor test results in terms of the annual cost for any desired level of protection. The abscissa represents the annual cost of the rust inhibitor program, and the ordinate the percent rust protection, relative to the blank, which is obtained in the static conductometric test. It is assumed that, in this case, the static test corresponds most closely to service conditions. The curves represent rusting test data obtained with four different types of inhibitors, and the points correspond to various concentration levels. Thus, for example, 5 pounds of Type B inhibitor per 1000 barrels could be used at a relative annual cost of 60, and this would result in about 30 percent rust protection in the static test. Alternatively, 1 pound of Type D or of Type E inhibitor would each produce about 90 percent rust protection, but the cost of Type D inhibitor is three times greater than that of Type E. For the conditions of this test, it is now clear that any desired level of rust protection can be obtained at the least cost with Type E inhibitor. For that reason compounds of this type represent the best choice for field trials leading to large scale use.

Conclusion

In order to make a wise selection of rust inhibitors on the basis of accelerated laboratory tests, it is necessary to obtain accurate, quantitative laboratory test data under conditions approximating those which exist in the field. These data then can be interpreted in terms of the cost involved and the degree of protection desired. The Indiana Conductometric Rusting Test described here provides the type of data required for such an analysis. The test is accurate, sensitive, and reproducible, and detects small differences in inhibitor performance that cannot be observed by visual rusting tests.

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6. G. A. Marsh and E. Schaschl. *Corrosion*, **12**, 534t (1956) Nov.
7. W. L. Terrell and W. L. Lewis. *Corrosion*, **12**, 491t (1956) Oct.

Any discussion of this article not published above will appear in the June, 1957 issue.

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Study of a Size Effect in Galvanic Corrosion*

By JAMES T. WABER

Introduction

THIS PAPER is more a theoretical than a practical study of the behavior of galvanic cells and relates to the distribution of potential and current over each of electrodes of the system. Although many geometrical arrangements of electrodes are possible, only those in which the anode and cathode lie in a common surface will be considered. This arrangement was chosen because it is more pertinent to the microelements that are present on a commercial metal. The other commercially important arrangement, (i.e., where the anode and cathode lie in separate planes and "face" each other, such as in a battery or in electroplating) will not be discussed.

The distribution of the potential within the corrodent will receive primary consideration because it is the driving force of corrosion. In addition it is the one measurement most commonly used[1] in corrosion studies which can be varied almost at will. For example, it is frequently used to decide whether or not corrosion will occur in cathodic protection practice. However, later in this paper, the distribution of the corrosion currents over each electrode will be discussed to emphasize the salient features of the "size effect."

Potential of a Metallic Couple in Solution

The potential within an entire galvanic system is schematically represented in Figure 1. This is similar to a scheme in a recent translation of a chapter of Akimov's book which appeared in *Corrosion*[1] and is an elementary representation of the principal facts. Here and in the later sections, the anode will be regarded as more positive than the cathode as far as the internal positive ion flow is concerned. Faraday defined the anode as the place the positive ions enter the cell or solution and the cathode as where they leave it.

In the external or metallic conductor circuit, the anode is more negative as it has an excess supply of electrons left in the metal as positive ions dissolve (i.e., left by the anodic reaction.) The electronic current flows down the potential gradient toward the more positive (external) terminal, the cathode, as shown. The anode lies to the left of the cathode. These notations follow the most recent sign convention adopted at Stockholm and discussed by de Bethune.[2] The gradients of the two potentials in the branches of the circuit are drawn with the same sign

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(1) Although weight loss or gain is perhaps a more common measurement, it is the end result of corrosion in the sense that to change it one must be able to modify the environment and essentially understand the process.

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Abstract

Distribution of potential within a corrodent was analyzed using several geometric arrangements of electrodes which lay in a common surface. Polarization was assumed to follow Wagner's useful relation as it varied from point to point on the electrode in response to the local corrosion current. The distribution of the corrosion attack over the anode also was studied.

It was found that there was a size effect in the galvanic corrosion studied with the detailed behavior depending to a great extent on whether the electrodes were larger or smaller than Wagner's polarization parameter. It was found also that the potential of a galvanic couple depended on the relative areas of the two electrodes, as well as on their open cell potentials. 3.8.2

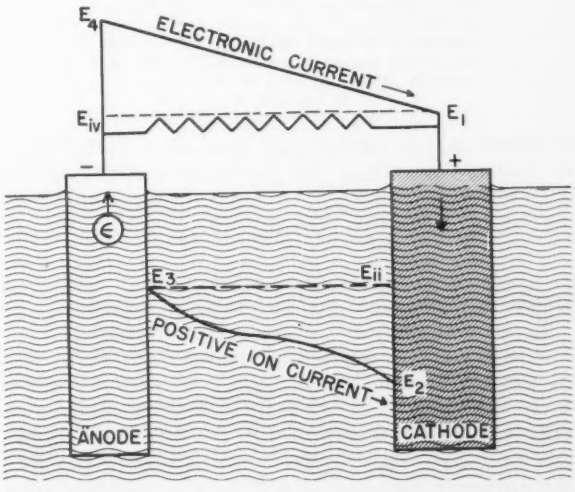

Figure 1—Schematic drawing of a galvanic cell with the external resistance indicated. Increasing potential is plotted vertically. Arrows indicate the direction of electronic and cationic flow.

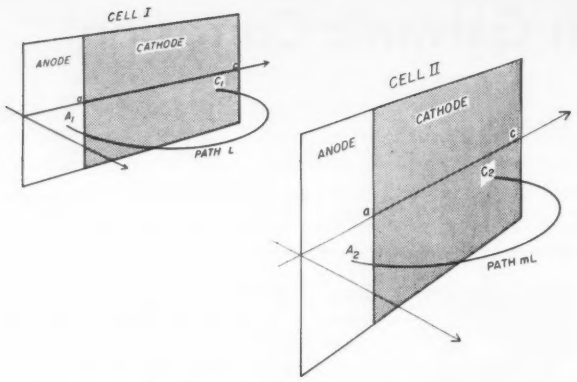

Figure 2—Two model galvanic cells differing in size which are immersed in a common electrolyte. Path between two arbitrary points is indicated. The location of these points and the dimensions of cell are assumed to be geometrically similar.

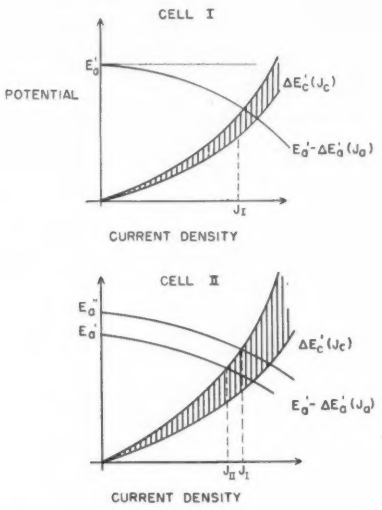

Figure 3—Evans' polarization diagram for the two cells. The crosshatching indicates the V_{drop} appropriate to each current density for arbitrary paths. In the upper diagram, the current density corresponding to path is designated J_I, but at this current density V_{drop} exceeds the available voltage in Cell II. Either the current density must drop to J_{II} or the net potential of the cell must be increased to E_a'' to maintain J_I.

since the charge carriers are assumed to be different in the two branches. To this extent this diagram differs from that used by Akimov.[1] In an active cell, the active or effective potential difference is

$$(E_{II} - E_2) + (E_4 - E_{IV}) \qquad (1)$$

where these voltages are identified in Figure 1.

In general, the resistance in the external portion of the current is negligibly small when one is discussing local cell action, since the electrodes are short circuited. The effective potential reduces to $(E_{II} - E_2)$ and corresponds to the "IR drop" inside the electrolyte due to the current flowing between the electrode surfaces. It will be the distribution of this potential which will be discussed in this paper. The potential gradient within the solution or corrodent will, in general, not be constant as is more usually the case where the electrodes "face" each other.

Polarization and Potentials Considered

The potentials at E_2 and E_3 (or E_{II}) can be defined if there is a finite concentration of ions in the corroding solution. There is a well-defined equilibrium electrode potential E_3 which can be measured as the voltage of the following cell when no current flows between the anode and cathode.

Standard Hydrogen Electrode	Salt Bridge	Corrodent Solution	Anode Metal

However, when the cell is active and appreciable currents flow, the potential is no longer that for equilibrium. Nevertheless, the *local* electrode potential at some point (x) in the solution and adjacent to the surface of the anode, namely P(x), is defined as the voltage of an identical cell where the opening of the capillary to the reference electrode is located near point x of the anode surface. Measurements of local single electrode potential have been made by Copson[3] and by Jaenicke and Bonhoeffer.[4]

Let V_a represent the uniform potential of the anode relative to the standard hydrogen electrode. When point x is near the anode surface the potential difference $V_a - P(x)$ may be written as a sum of the equilibrium single electrode potential E_3 and a polarization term $\Delta E_a(J)$. The latter symbol represents the dependence of the anodic polarization on the *local* anodic current J(x) at point x. That is

$$E_3 - \Delta E_a(J_a) = V_a - P(x) \qquad (2)$$

According to Ohm's law

$$J(x) = K\left(\frac{\partial P}{\partial n}\right) \qquad (3)$$

where K is the electrical conductivity of the solution and (dP/dn) the local normal gradient of the potential evaluated at this point.

Size Effect

This treatment parallels that given by Agar and Hoar.[5] Consider two galvanic cells depicted in Figure 2. It is assumed that they are immersed in the same electrolyte and are composed of the same two anode and cathode metals. The total EMF arising in the circuit must overcome:

(a) The resistance of the electrolyte,
(b) The polarization at the two electrodes,
(c) The resistance of the films present on the electrodes, and
(d) The metallic resistance of the external circuit.

It has been assumed that (c) and (d) are so small that they can be ignored so that all points within the solid portion of each electrode are at the same potential. Let ΔE_a and ΔE_c be the polarization occurring at arbitrarily chosen points A and C on the two electrodes. Then the effective voltage E_a' is composed of these two overvoltages and the "IR drop" along the path (indicated in the upper part of Figure 2), which lies entirely in the solution.

The positions of A_2 and C_2, as well as the widths a_2 and c_2, are chosen so that the two cells are similar in the strict geometric sense. Assume that the cell II is m times as large as the smaller one. Then if the path length in the smaller cell is L, the path length in the other is mL. The voltage drop along the path in cell I is given by

$$V_{drop} = \frac{L}{K} D \qquad (4)$$

where as before K is the specific conductivity and D is a mathematical quantity appropriate to this path.[2]

Temporarily E_2 or E_c' will be set equal to zero so that the effective driving force or potential difference E_a' is

$$E_a' \equiv E_3 - E_2 = E_3$$

This reference point on the potential scale will be shifted later when the quantity E_a is defined. The effective driving force overcomes the two polarizations and the "IR drop." Thus by reference to Figure 3

$$E_a' = \Delta E_a' (J_a) + \Delta E_c' (J_c) + (LD/K) \qquad (5)$$

in cell I. However, $m > 1$ and

$$E_a' \leqq \Delta E_a' (J_a) + \Delta E_c' (J_c) + m (LD/K) \qquad (6)$$

in the larger cell. In both portions of this figure the vertical cross-hatching corresponds to V_{drop}.

If the current densities at A_2 and C_2 are the same as at A_1 and C_1 the anodic and cathodic polarizations will be the same. Thus E_a' will be insufficient to overcome these and the increased V_{drop}. The current can be maintained by increasing E_a' to E_a'' as indicated in Figure 3. For all practical purposes E_a' is fixed by materials and the corrodent and cannot be varied at will. Most frequently, the equality in Equation (6) can apply only if the current is reduced.

It has been assumed that the anode and the cathode themselves are equipotential, but the solution in intimate contact with them will usually not be equipotential owing to the variation of the local current density from point to point on the electrode surface. If Cell II were a "true" model of Cell I, the current densities and potentials due to overvoltages would be the same at all corresponding points in the two cells. Because of the factor in Equation (6), it is clear that II cannot in general be a faithful representative of I.

In the field of corrosion, the effective driving force, E_a', is determined by the open circuit potentials and the polarization curves of the components. Thus for the purposes of this paper it can be regarded as constant. Since all the terms in Equation (5) are positive, V_{drop} must be less than E_a'. If L is very large, the current density will be small because the resistance is high and both ΔE_a and ΔE_c will be small. Thus

$$V_{drop} \sim E_a' \qquad (5a)$$

and therefore the polarization is negligible in a very large cell as mentioned by Kasper.[6] The magnitude of the current is controlled by the resistance of the corroding solution and its distribution (in this *macroscopic* cell) approaches that which would be observed with unpolarizable electrodes.

If in contrast, one makes m so small that the resistance along the path mL is negligible, one ultimately reaches the condition where

$$\Delta E_a' + \Delta E_c' \cong E_a' \qquad (5b)$$

and the magnitude and distribution of the current density are controlled by the polarization. If the electrodes are homogeneous in the sense that the anodic polarization curve (as a function of current density) is identical at all points on the anode and the same is true of the cathodic polarization curve, then the current density is uniformly distributed over each electrode. This is an important characteristic of a *microscopic* cell.

It is suggested by Equations (5) and (6) that a large and a small cell might be models of each other if (m/K) could be kept constant. Then the current density and consequently $\Delta E_a' + \Delta E_c'$ would remain fixed. The conductivity of K of the corrodent would have to be adjusted to achieve this result and it seems likely that this could not be done without affecting either the potentials or the polarization curves. This reasoning indicates that the physical size of electrodes does not exclusively determine the behavior of the galvanic system (i.e., the distribution of current). This follows because even with m large if the conductivity is made high enough, (m/K) can be small and thus the cell behavior would be similar to that of a microscopic system.

The effect of current density on $\Delta E_a'$ and $\Delta E_c'$ is also important. As first pointed out by Pfannhauser,[7] the higher the slope of the polarization curves, the more uniform the current distribution. (It might be mentioned, however, that Pfannhauser was concerned with electrodeposition and not corrosion). Thus if $\Delta E_a'$ plus $\Delta E_c'$ becomes equal to E_a' at very low current densities, the voltage drop for any path becomes insignificant and any variations of resistance within the electrolyte due to different geometric arrangements of the electrodes become of lesser importance. It is as though each element of the electrode surface were provided with a high (non-linear) resistance in series with the electrolyte resistance when the slope is large. The system appears to be behaving *microscopically*.

Polarization Parameter

These considerations show that both the slope of the polarization curves and corrodent conductivity influence the distribution of current within a galvanic cell as mentioned by Kasper.[6] Apparently it was first pointed out by Hoar and Agar[8] that the product of K with the slope of a polarization curve has the dimension of length. Wagner[9] more formally defined this length, known as the polarization parameter, to be

$$L_i = K \left| \frac{\partial \Delta E_i'}{\partial J_i} \right| \qquad (7)$$

[2] Specifically, D is the following line integral $D = \int J_a \cdot ds$ where J_a is the component of the current density along the line at any point.

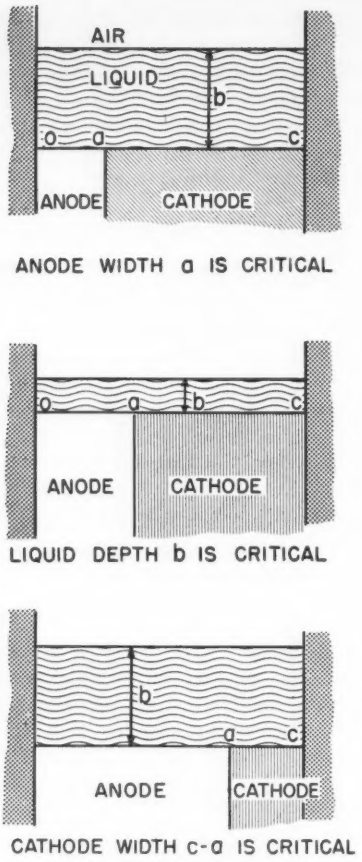

Figure 4—Cross-section through a plane galvanic cell. The drawings illustrate when each cell dimension becomes the critical one.

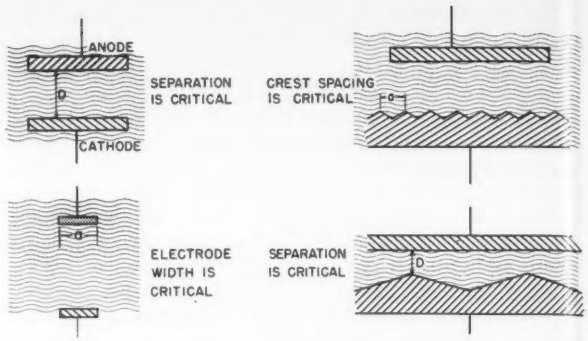

Figure 5—Cross-sections through two typical electrolysis cells. Drawings illustrate the critical dimension for each case.

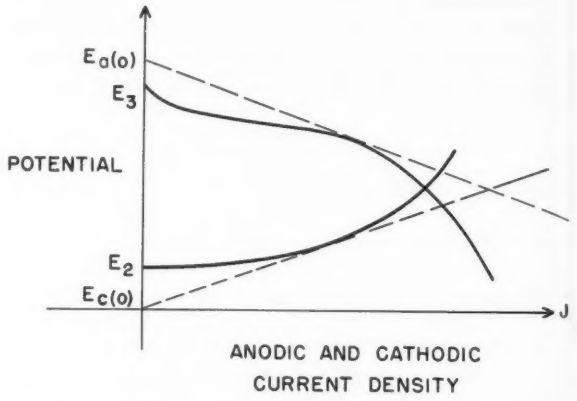

Figure 6—Illustration of the tangent approximation to the polarization curves. The extrapolated potentials $E_{a(o)}$ and $E_{c(o)}$ are distinct from the open circuit potentials E_2 and E_3.

where the subscript i stands for either anode or cathode. The vertical bars in this equation are a mathematical notation for the magnitude (or absolute value) of the quantity inside.

Loose relative terms such as "very large" have been used to describe galvanic cells above. However, this polarization parameter serves as a standard length for comparing various galvanic cells. If mL is much greater than $\mathbf{L}_1$, the cell will behave as though it were made of unpolarized electrodes. In contrast, if mL is much smaller than $\mathbf{L}_1$, the current is uniformly distributed and the cell is "microscopic."

Note that the positions of A_1 and C_1 in Figure 2 are arbitrary; they could have been chosen very close to the anode-cathode junction, in which case L would have been infinitesimally small. In such a case mL would have been less than **L** whereas the path between two different points in the cell might be considerably larger than **L**. This emphasizes that some dimension of the cell is required for characterizing it rather than an arbitrary path in the corrodent.

Critical Dimension

Such an appropriate physical dimension of the cell will be designated as λ, the critical dimension. It can be defined as that dimension of the cell which most strongly affects the distribution of current density over the electrode surface. Generally speaking, it will be one of the smallest dimensions of the cell.

For example, the cross-section of a galvanic cell is shown in Figure 4. Assume that the anode and cathode are quite long in the direction perpendicular to the paper but are not very wide. The cell might be contained in a long thin battery jar. The anode is *a* units wide, and the cathode is *(c-a)* units wide. The corrosive solution is sitting on the electrodes and is *b* units deep. This figure illustrates when each of the cell dimensions becomes the critical one. How these quantities affect the current density distribution has been discussed by Waber.[10] Two typical electrolysis or electrodeposition cells are depicted in Figure 5 and the critical dimension is illustrated. Note that the spacing of the very rough saw tooth can be the critical dimension and not the total width of the electrodes. These points have been discussed by Wagner.[9]

Condition for Model Experiments

Now that the critical dimension λ and the polarization parameter **L** have been defined, one can formulate the condition under which one can use a laboratory cell as a model for a full-scale experiment. Two geometrically similar cells will be faithful models of

each other if the ratios of λ to **L** are equal. This important condition has not been generally recognized. Virtually no corrosion tests have been designed to date with this condition in mind.

If the electrical resistance of the corrosive medium is high or if **L** is small in comparison to λ, due to a low slope in the polarization curve, the system can be analyzed satisfactorily by assuming negligible polarization. When $(\lambda/\mathbf{L})$ is large, the cell is called "macroscopic." On the other hand, under corrosive conditions that permit strong polarization of the electrodes (**L** is large) even very macroscopic electrodes may behave as though they had microscopic dimensions. "Microscopic" galvanic cells are characterized by relatively uniform distributions of the current density.

Estimation of the Polarization Parameter

Equation (7) must be used to calculate both the anodic and cathodic polarization parameter. When the cathodic process is the evolution of hydrogen, the equation may be simplified since the logarithmic form of the overvoltage curve known as Tafel's equation applies. Without going into details, the cathodic polarization parameter is given by:

$$\mathbf{L}_c \cong \frac{K}{20\, J_c}$$

where J_c is in amps/sq cm and K is in reciprocal ohms per centimeter. This polarization parameter varies from a fraction of a millimeter to slightly more than 3 cms. Typical values of $\mathbf{L}_c$ as well as the anodic $\mathbf{L}_a$ are given in Table I.

This wide range of sizes suggests that unless the polarization curves have been determined under service conditions, the polarization parameter cannot be accurate.

The extrapolation of data obtained on beaker-sized galvanic cells to galvanic cells involving, for example the hull and the propeller of a ship, may be unwise. On the other hand, laboratory specimens seldom need to be larger than a meter to simulate large service equipment. This statement is based on the supposition that **L** will be less than 4 inches or 10 cms in any corrosive medium. However, larger values may conceivably be found in the course of time.

Approximate Polarization Curves

To facilitate mathematical treatment of galvanic cells, Wagner[9] and others[10,11] have used a linear approximation to the polarization curve which is sufficiently accurate as long as the local current densities do not vary radically from one part of the electrode to another. One can visualize the situation by referring to an Evans' polarization diagram. In Figure 6, the curves for the anodic polarization of the anode and cathodic polarization of the cathode are plotted as functions of the current density J. Although they are found to be straight lines in many cases, this is not necessary. Tangents are then drawn to these curves at some appropriate current density, such as the mean of the local values and these tangents are extrapolated back to intersect the ordinate

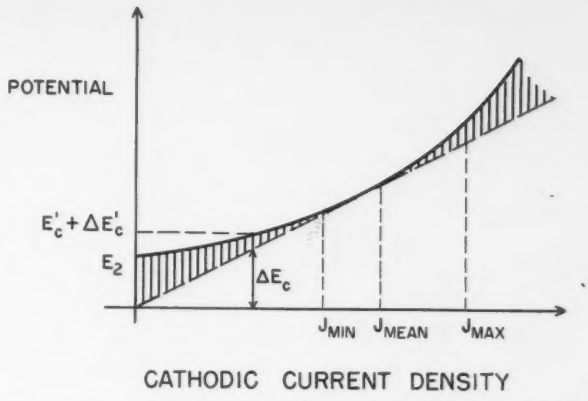

Figure 7—The distinction between the potential of the polarized cathode and the approximate value is given by the linear or tangent curve. The error is indicated by crosshatching.

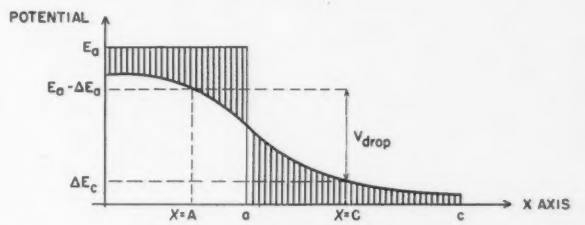

Figure 8—Variation of the interfacial potential along the electrode surface. The polarization as well as the V_{drop} along path L in Cell I is depicted schematically.

TABLE 1—Calculated Values of the Polarization Parameter

Solution Employed	Metal Involved	Parameter (cm)
0.5 M lead perchlorate	Lead	0.05[1] (75 C)
0.5 M lead perchlorate	Lead	0.14[1] (50 C)
1 M cupric perchlorate	Copper	0.3[2]
3% NaCl + 0.25% H_2O_2 + 0.6 N HCl	Zinc	<0.02[3]
20% CrO_3	Zinc	1.12—3.12[4]
Bayonne tap water	Steel	0.41—2.54[5]
Bayonne tap water	Nickel	0.81—2.41[5]
150 g zinc sulfate per liter + $B(OH)_3$	Zinc	0.006—0.08[6]
45 g $K_2Zn(CN)_4$ + 15 g KCN + 20 g NaCl + 20 g NaOH + 1000 g H_2O	Zinc	0.22—2.3[6]
3% NaCl + 0.25% H_2O_2 + 0.6 N HCl	Zinc	0.4—2.5[3]
0.2 N K ClO_3	Zinc	0.21[7]
0.05 N K Cl	Zinc	0.78[7]

Note: Top six lines are anodic values and bottom six lines are cathodic values.
[1] Calculated by Waber[11] from data of Pointelli and Poli[13].
[2] Calculated by Waber[11] from date of Pointelli and Poli[14].
[3] Calculated by Waber[10] from data of Akimov and Golubev[15].
[4] Calculated by Hulme[16].
[5] Calculated by Waber from date of Copson[3].
[6] Calculated by Wagner[9] from data of Mantzell[17].
[7] Calculated by Waber[12] from data of Daniel-Bek[18].

at $E_{a(o)}$ and $E_{c(o)}$. These intercept voltages are, in general, very different from the respective equilibrium voltages E_a and E_c. The zero point for the potential scale is now selected for convenience at $E_{c(o)}$ and the effective potential difference E_a is defined as

$$E_a \equiv E_{a(o)} - E_{c(o)} \qquad (9)$$

Note that this quantity is different from the effective driving force E_a', used above. The latter has more fundamental significance.

There is a simple relation between the true and

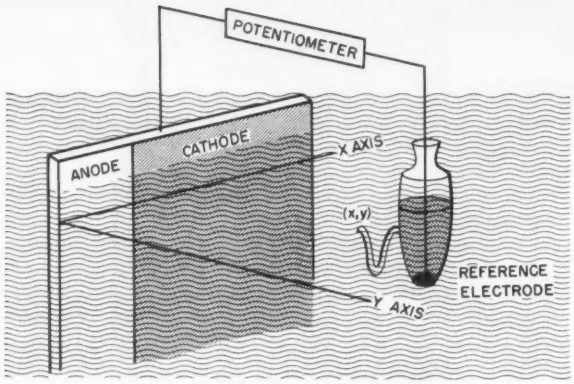

Figure 9—Typical potential measuring circuit.

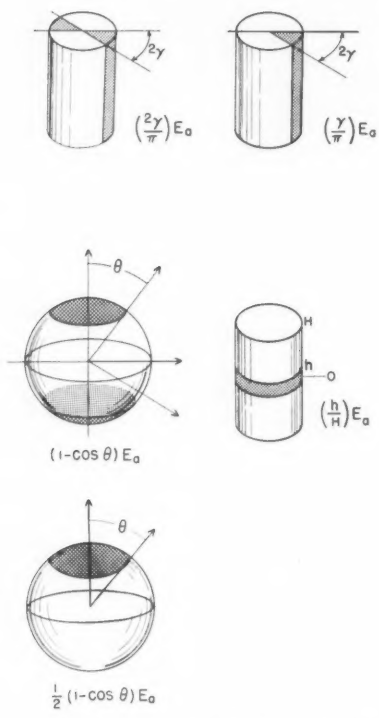

Figure 10—Potential of the composite electrodes is shown for five different electrode geometries. The anode is the darker area. These drawings illustrate that the potential is proportional to the area fraction of anodic material.

these approximate, linear polarization curves. If E_2 is the equilibrium potential of the cathode and $E_{c(o)}$ the intercept of the tangent drawn at the mean current density J_{mean}, then as Figure 7 illustrates

$$E_2 + \Delta E_c'(J) \cong \Delta E_c \qquad (10)$$

where ΔE_c is the estimated cathodic polarization at current density J. The crosshatching in this figure illustrates the error in this approximation. If the minimum J_{min} and the maximum current densities are not very different from the mean, the estimated overvoltage ΔE_c is only slightly too small. Similarly, the anodic polarization can be shown to be

$$E_3 - \Delta E_a'(J) \cong E_{a(o)} - \Delta E_a \qquad (11)$$

where ΔE_a is the estimated anodic overvoltage at the current density J.

Both of these approximate overvoltages can be computed from the equation

$$\Delta E_i = \mathbf{L}_i J_i / K \qquad (12)$$

where the subscript i has the same significance as in Equation (7). For many of the computations and derivations made to date, $\mathbf{L}_a$ has been assumed to be equal to $\mathbf{L}_c$. Waber[12] has indicated which (other) mathematical studies have been made where the polarization parameters were widely different.

The variation of potential along the x-axis (in Figure 2) which is perpendicular to the junction, is illustrated in Figure 8. The voltage drop V_{drop} between points A and C is indicated schematically.

Returning now to Figure 7, this approximate method of dealing with polarization works most accurately if the ratio (J_{max}/J_{min}) is not large, which is the case if $\mathbf{L}$ is much larger than the critical dimension. In such "microscopic" cells, polarization is much more important than the resistive drop V_{drop}. Macroscopic cells have large variations in current density and although (J_{max}/J_{min}) is very large, polarization is relatively unimportant. Thus the linear approximation holds best in those cases where polarization is most important, and breaks down in those cases where the electrodes act as though they were unpolarized.

Potential of Composite Electrode

The usual electrode potential measuring circuit is shown in Figure 9. It is common experience that the potential P(x,y), which is measured by locating the capillary tip of a reference electrode at point (x,y), varies from point to point in the corrosive medium, and that if the point (x,y) is far enough from the electrode surface the variation of potential with position becomes negligibly small. Schwerdtfeger and Denison[19] have called such a large distance the effective electrical boundary and have assumed that beyond it the potential of the galvanic system has an (essentially) uniform value. How small are negligibly small variations? It is a matter of subjective opinion and is conditioned by the precision of the measuring equipment at hand.

This uniform potential observed beyond the effective electrical boundary has been called the potential of the composite electrode by Waber and his coworkers,[10,11,12,20,21] who have dealt with plane electrodes. In some unpublished work,[22,23] this quantity has also been derived for spherical and cylindrical electrode systems where both the anode and cathode lie in the common, curved surface. Values of the potential and their pertinent electrode system are illustrated in Figure 10.

If three plane electrodes are involved in the system, the potential of this composite electrode is shown in Figure 11. This three-element system can be reduced to an equivalent two-element system by

setting E_b either equal to zero in which case the composite potential becomes $(a/c)E_a$, or by setting it equal to E_a in which case the potential becomes $(b/c)E_a$.

In all these cases studied, the potential of the composite electrode is equal to

$$\left\{\frac{\text{(area of anode)}}{\text{(area of anode plus cathode)}}\right\} E_a \qquad (13)$$

In the two and three electrode systems, as long as the metallic strips are each M units long in the direction perpendicular to the paper, the ratio of areas will be equal to the ratio of their widths. When the cylindrical arrangement consists of a cylindrical ring anode imbedded in a longer cylindrical cathode (of the same radius) the ratio of areas is equal to the ratio of heights, namely (2h/2H) or (h/H). When the anode is wedge-shaped, the ratio of areas is equal to δ/π where the angle δ is in radians, since the area of a pie-shaped cut of a circle is δr^2. When there are two wedge-shaped anodes, the ratio is $2\delta/\pi$.

In the spherical case, the area of an anodic cap is $2\pi rh$ where h is the altitude of the cup. If the cap is included by the colatitude angle Θ, the altitude h is $r(1-\cos\Theta)$. Thus the ratio of areas is $2\pi r^2(1-\cos\Theta)/4\pi r^2$ if there is only one cap and is twice that if there are two caps.

Thus in all of these systems, the potential at infinity (i.e., that of the composite electrode) is the anodic fraction times the effective potential difference E_a. The mathematical analysis was subjected to the condition that the anodic value of **L** was equal to the cathodic value. While this condition is not true in all practical situations, it is not a very stringent condition when one is discussing such a variety of geometric arrangements.

The implication of this result is that when one is measuring a potential, the value obtained is dependent upon the relative amounts of anodic and cathodic material as well as on their open-circuit potentials. If the electrode metal is not pure, the measured potential will reflect this.

Distribution of Current

The question of distribution of current is too difficult to present adequately here since there is an interplay between the cell dimensions and the polarization parameter. For example, in a plane cell with a given anodic width *a* and an electrolyte depth of *b*, the characterizing ratio may be (*a*/**L**). However, as the liquid depth is greatly reduced so that *b* is very much smaller than *a*, it becomes the critical dimension. Numerous graphs are needed to fully illustrate this interplay.

Assuming that *a*/L is fixed, one can see what happens to the current distribution as the cathodic width increases. The ratio of the (approximate) maximum anodic current density near the anode-cathode junction to the minimum anodic current density at some point remote from the junction, have been computed and is presented in Tables 2 and 3. The latter table is computed for an infinitely large cathode. The ratio is low in "microscopic" cells, for instance

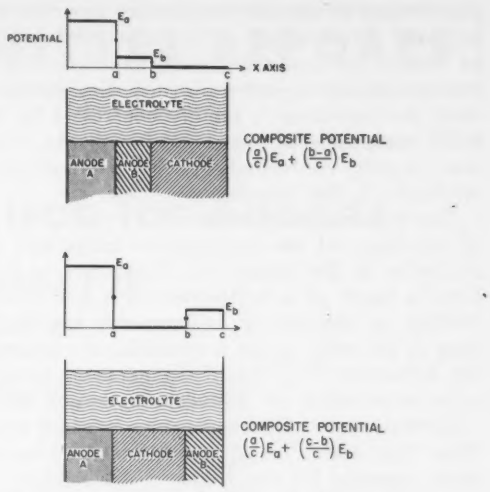

Figure 11—Potential of the composite. A three electrode system is depicted for two arrangements.

TABLE 2—Ratios of the Approximate Maximum to the Minimum Corrosion Current Density

a/L	a/c = ¾	a/c = ½	a/c = ¼
0.05	1.16	1.04	1.03
0.5	2.75	1.38	1.52
5	22.0	5.22	4.40
10	.....	9.68	.....
50	181	41.7	31.4
100	.....	73.2	.....
∞	765	318	132

TABLE 3—Ratios of Maximum to Minimum Current Density for an Infinite Cathode

a/L	J_{max}/J_{min}
0.01	1.0045
0.1	1.05
1	1.59
5	4.44
10	8.26
100	79.0

with (*a*/L) set at 0.05, but rapidly increases as (*a*/L) becomes 50 and the cell becomes "macroscopic." A large value of the ratio indicates a very non-uniform distribution of the current density characteristic of unpolarized electrodes.

Discussion and Summary

The behavior of galvanic cells has been described in terms of a "size effect." In order to do this, one must introduce the concepts of a critical dimension λ and a polarization parameter **L**. It was pointed out that irrespective of its physical dimensions, a galvanic cell may behave as though it were "microscopic or "macroscopic" depending on whether the ratio of λ to **L** is small or large.

The critical dimension of a cell can be defined as that one which affects the distribution of current density most strongly. In general, it is one of the smaller cell dimensions such as the separation of electrodes or the depth of electrolyte.

A "microscopic" cell is characterized not only by a low (λ/**L**) ratio, but also by a relatively uniform

distribution of the current density over the electrode surfaces. In contrast, a "macroscopic" cell behaves as though its electrodes were unpolarizable and the current density is not uniformly distributed. In this case, the corrosion is mainly controlled by the electrical resistance of the corrosive media, whereas it was largely controlled by the polarization of the electrodes in the "microscopic" case.

The polarization parameter is equal to the product of the slope of the polarization curve and the conductivity of the electrolyte. It ranges in dimension from a tenth of a millimeter to a few centimeters. Scaling up laboratory experiments can be done as long as the ratio ($\lambda/\mathbf{L}$) is equal for the laboratory and for full-scale "field test." In general, however, the experiment done on a laboratory bench will not be a faithful model of the tests done in plant equipment. This "size effect" may account for one more of the many reasons for the frequent discordance between laboratory and pilot plant experiments.

The use of the linear approximation to the polarization curves has been described and it has been pointed out that it works best in galvanic systems which are behaving "microscopically." That is, it works best in those systems in which polarization effects are dominant.

The potential of a composite electrode is dependent on the relative areas of the two electrodes (which lie in a common plane) as well as on the open cell potentials of the components.

Notations Used

V_a = uniform potential of the anode at equilibrium.
V_{drop} = potential drop along a path laying in the corrodent.
$P(x,y)$ = potential at any point (x,y) in the solution.
E_a' = effective potential difference (driving force) between the anode and cathode.

The symbols $E_{a(o)}$, E_a and ΔE_a pertain to the linear approximation employed while E_2, E_3, $\Delta E_a'$ and $\Delta E_c'$ are steady state non-equilibrium potentials and potential differences.

Acknowledgment

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Any discussion of this article not published above will appear in the June, 1957 issue.

NACE TECHNICAL COMMITTEE REPORTS

First Interim Report **Publication 57-4**

Use of High Silicon Cast Iron for Anodes

NACE Technical Unit Committee T-2B
On Anodes for Impressed Currents*

Prepared by Task Group T-2B-4 on High Silicon Cast Iron Anodes*

Abstract

Reports of data received in reply to questionnaires circulated by the task group are reported. Data indicate high silicon cast iron anodes can be expected to perform satisfactorily both with and without coke breeze ground beds and that economics of installation without ground beds frequently is good. Difficulties were reported from chlorine gas blocking when anodes were installed in environments with high chloride content, including drastic reduction in service life.

Successful installations in fresh, brackish and salt water are reported. Temperatures up to 200 F appear not to be significant in fresh water and variations in pH from 3 to 10 have no marked influence on wastage rate. In high chlorine fresh waters heavy wastage is reported at temperatures in the range 150-160 F. In sea water or brackish waters with high chloride content heavy attack occurs at temperatures over 150 F.

5.2.3

Introduction

TASK GROUP T-2B-4 was assigned on August 30, 1955, the work of correlating information on high silicon cast iron anodes. Over 100 questionnaires were distributed to companies having these anodes in service and many other known users were not contacted because detailed service information was available to the committee already.

Approximately 75 percent of those contacted gave information on their work. While some replies provided no immediately useful data, the majority proved very helpful. Installations in many cases were too recent to provide anything other than a general description of the project and the initial electrical characteristics.

Because of the large number of replies received, it was not considered practical to summarize each reply separately. Therefore only the general trend of results is given in this report.

Although all replies were not in complete agreement a clear trend was established on the most important points where conflicting data were at a minimum. A few reports on installations are summarized in some detail to illustrate a particularly important point.

For convenience results are subdivided into three general categories: Ground bed, fresh water and sea water. Each category will be considered separately and discussed in detail.

Ground Beds

Approximately 35 individual files were compiled on ground bed applications. Many of these files involved more than one ground bed containing high silicon iron anodes. Numerous installations were made with anodes surrounded by tamped coke breeze and it was the consensus that no electrical difference exists between a ground bed made with graphite and one made with high silicon iron.

Table 1 illustrates the comparison between high silicon iron and graphite anodes under varying conditions, mainly with coke breeze backfill. The concept that the central rod or anode merely serves as the electrical contact with the larger backfill anode was substantiated in this work. Numerous instances were cited where either additions to an existing graphite ground bed were made or a new bed was installed using both materials and the anode resistance and current discharge from both materials were of the same magnitude.

In most instances 1½-inch or 2-inch diameter x 60-inch sizes provided the same results. Therefore, the single anode resistance of a high silicon iron anode in a 10-foot column of backfill 1 foot in diameter is given by the expression R equals 0.002ρ where ρ is the resistance of the earth in ohm-centimeters.

Backfill materials other than coke breeze cannot be recommended because the two attempts reported did not give satisfactory results. In one instance gypsum was tried as a backfill material. It did not lower the anode resistance appreciably and wood fiber plaster backfill reacted similarly. The latter will be checked at a later date when a follow-up of these installations is made. All laboratory and field tests indicated that wet or dry coke breeze had no deleterious effect on the high silicon iron material. In well tamped coke breeze consumption rates on high silicon iron were sufficiently low to indicate 20 years' service or more.

Because high silicon iron appears to have no practical current density restrictions in ground bed service it has been substituted sucessfully for other anode materials in many difficult services. When so used

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consumption rate on high silicon iron increased although it was still in the acceptable range as illustrated below:

Variable Water Table

Two 4-inch diameter x 80-inch graphite anodes originally installed in a vertical position in coke breeze backfill to protect a lead sheathed telephone cable failed after three-four years. Failure occurred at a point approximately 6 inches from the top of the anode and the lower end also was heavily attacked. This apparently indicated a varying water table which often saturated the coke breeze causing uneven current discharge. Graphite anodes were replaced with two 1½-inch diameter x 60-inch silicon iron anodes and the same electrical characteristics (3 amperes at 27 volts) were achieved. After one year's service the high silicon iron anodes were removed and inspected. Consumption rates of 0.75 and 0.93 pound per ampere year were measured, indicating many years' successful operation could be expected at the current densities prevailing.

Installation in Quicksand

A ground bed of nine graphite anodes originally installed in river bottom quicksand supplied protection to a gas transmission line. Quicksand was encountered at six feet making it impossible to maintain an open hole. Accordingly the lower two feet of the anode was pushed into the quicksand and the upper three feet was surrounded by tamped coke breeze. The anodes were arranged in a single row at 30-foot spacings with an initial current output of 30 amperes at 40 volts for a total loop resistance of 1.33 ohms. After approximately 15 months' time it was noted that the current had dropped to six amperes. An examination revealed the lower parts of all anodes were completely destroyed. The bed was abandoned and an identical one constructed nearby using 2-inch diameter x 60-inch silicon iron anodes with the lower two feet in quicksand. Initial current output was 20.7 amperes at 39 volts for a loop resistance of 1.91 ohms.

During the next five months the resistance steadily decreased to 1.10 ohms (34.6 amperes at 37.9 volts). The decline in loop resistance indicated that soil conditions were not typical immediately after installation. After one year readings on the high silicon iron anodes were 37.0 amperes at 36.5 volts. A first year average of 33.3 amperes, 36 volts, or a loop resistance of 1.08 ohms was obtained from this installation.

Three high silicon iron anodes removed after one year's service operated at an average current of 1.24, 1.48 and 1.63 amperes and showed a consumption rate of 0.73, 1.10 and 0.31 pound per ampere year respectively. This was an average of 0.71 pound per ampere year for the three. Based on these first readings the bed should last more than five years or approximately five times longer than the original installation.

TABLE 1—Comparison of High Silicon Iron (HSI) Anodes and Graphite (G) Anodes Under Identical Ground Bed Conditions
All Anodes Vertical Except Tests 1 and 2

Test No.	Anode Description Dimension in Inches	Location	Backfill	Average Current/ Anode Amperes
1	1—HSI, 2x60 18—G, 2x80	Soil Soil	Coke Breeze Coke Breeze	1.5 1.25
2	4—HSI, 1½x60 4—G, 3x60	Moist Soil Moist Soil	Salt used in Soil Salt used in Soil	1 2
3	1—HSI, 1x60 1—G, 3x60	Soil Soil	Coke Breeze Coke Breeze	4.5 4.2
4	10—HSI, 2x60 5—G, 3x60	Swamp Swamp	None None	1.4 1.4
5	1—HSI, 2x60 1—G, 3x60	Soil Soil	Coke Breeze Coke Breeze	3.2 2.8
6	1—HSI, 2x60 1—G, 3x60	Soil Soil	Coke Breeze Coke Breeze	4.4 4.0
7	3—HSI, 2x60 3—G, 3x60	Soil Soil	None None	1.7 1.9
8	1—HSI, 1x60 1—G, 3x60	Soil Soil	Coke Breeze Coke Breeze	4.7 4.3
9	4—HSI, 2x60 8—G, 3x60	Soil Soil	Coke Breeze Coke Breeze	1.9 1.6
10[1]	1—HSI, 2x60[2] 1—G, 2x60[3]	Soil Soil	Coke Breeze Coke Breeze	0.5 0.6
11[1]	1—HSI, 3x60[4] 1—G, 3x60[5]	Soil Soil	Coke Breeze Coke Breeze	0.65 0.5

[1] Anodes were located at different depths which had different soil resistivities as noted.
[2] 21,500 ohm-cm resistivity soil.
[3] 16,500 ohm-cm resistivity soil.
[4] 19,600 ohm-cm resistivity soil.
[5] 25,500 ohm-cm resistivity soil.

Use Without Backfill

High silicon iron is not immune to attack but because of its concentrated mass substantial life expectancy appears possible even under drastic conditions.

A relatively large number of high silicon iron anodes were installed without backfill of any type, in most cases where backfilling was not feasible. In other instances special techniques were employed for installing anodes rapidly and inexpensively. In these latter instances while it was realized a few more anodes might be required, their cost would be small compared to installation costs.

At the annual meeting of Unit Committee T-2B in 1955, a report[1] was made on a jetting technique for installing anodes using high pressure water. By this means 60-inch anodes were installed to an 8½-foot average depth in about one minute. Several installations have been made successfully using this technique.

After an additional one year's service the original bed of jetted anodes continued to show good output, indicating no tendency to gas blocking. Twenty 2-inch diameter x 60-inch anodes produced 36 amperes at about 43 volts.

Use of jetting techniques apparently is not restricted to soft soils because a report was received also of a similar technique used successfully in several types of soil including "Westchester Hard Pan" and heavy gravel, both of which are known to be very difficult to work. Jet installation takes more time in difficult soils but high silicon iron anodes still can be installed successfully.

Because installations without backfill require a somewhat larger number of anodes for the same total bed resistance, calculations were made on the single anode resistance using several high silicon iron anode sizes.

These calculations show that for a 2-inch diameter x 60-inch size the expression R equals 0.005ρ may be used and for the 1½-inch diameter x 60-inch size the expression R equals 0.006ρ holds. Two 1½-inch diameter x 60-inch anodes joined end-to-end with a stud, producing an effective length of 120 inches, correspond closely to the expression R equals 0.0035ρ. There were a few instances in which the single anode resistance of a bare anode did not approximate these formulas. In several instances where backfilling was not used the initial bed resistance continued to drop with time indicating that it may require an appreciable period for the soil to become well packed around the anode. In one case the bed resistance increased about 50 percent in a few months under seemingly uniform conditions. The jetting technique gives good initial contact. Good contact would be achieved also in water-saturated areas, such as swamps, rivers, crossings, etc.

Crowding Factor Minimized

While the resistance of a single bare anode is greater than for a backfilled anode the "crowding" factor is not as important. In reasonably uniform soil, anodes at a spacing of 25 diameters interfere to reduce the effect of the anodes to the exponent 0.75 of the number installed. For example, ten anodes in 12-inch coke breeze columns at 25-foot spacings would have a resistance equal to 5.6 independent anodes each with 1/5.6 of the resistance of a single anode. When the spacing is reduced to ten diameters the exponent is 0.45 while spacings of 100 diameters or more give a negligible interference effect. Thus it can be seen where a single bare high silicon iron anode has an effective resistance of about 2½ times that of a backfilled anode (using 2-inch size), a group of bare high silicon iron anodes compares more favorably. Twenty-foot spacing for 2-inch anodes is 120 diameters. At this distance there is virtually no interference and ten anodes have 1/10 the resistance of a single anode. The result is that only 40 percent more bare anodes are required to equal 10 backfilled ones. Other factors are involved but these favor utilizing bare anodes.

The above information has a varying significance to the average corrosion engineer. High silicon iron is adaptable equally to backfilled and non-backfilled installations and the same type of anode can be used in both. The material is suitable equally to swamp areas, river crossings and high resistivity areas where the anode often must be installed at greater depths than normal for best results. The 1½-inch size has been found most suitable for average backfilled jobs although under conditions where consumption is low a 1-inch anode may prove adequate. Where bare anodes are applied, 2-inch or two 1½-inch anodes joined end-to-end are best because they give added surface area and better electrical characteristics.

High silicon iron anodes also are being tested in soils where difficulty has been encountered previously with other materials. These include highly acid coal piles, clay soils with a high sulfate content and alkaline soils. In all cases no deleterious effects have been noted.

High Chloride Soils Troublesome

Greatest difficulty with high silicon iron has been experienced in high chloride soils. This point was mentioned at the committee's 1955 annual meeting. It was reported then that steps were being taken to determine the extent of the problem and possible means for rectifying or at least minimizing the difficulty. Results still are not entirely clear because the problem proved to be more complex than originally thought.

"Gas Blocking" Reported

In a few installations high silicon iron has been attacked by "gas blocking" with chlorine gas which resulted in anode attack. If the attack is selective it destroys the anode before the end of its useful life. In other instances anodes have operated with virtually no attack. A commercially available high silicon iron alloy containing molybdenum may possess desirable properties in chloride-containing environments. While one such alloy has given much better results in the few ground beds in which it has been applied, considerably more testing will be required before final conclusions can be drawn. Additional tests now are in progress. Although numerous attempts have been made to duplicate "gas blocking" in a laboratory, it was found to be virtually impossible if quantitative results were desired. It is possible to obtain localized attack under taped areas and while tests of this type gave a good indication of the resistance of a material to gas blocking, they do not indicate final recommendations. Such tests show superiority of alloys containing molybdenum because they do not corrode under the tape.

Fresh Water

High silicon iron has been used successfully in fresh water. It has been determined by laboratory tests that fresh waters corroded high silicon iron at rates approximating 0.25 pound per ampere year in the 0-3 ampere per square foot range. This rate appears to apply without respect to the pH of the fresh water because the same general results are observed at pH values ranging from 3 to 10.

Service results based on a two-year maximum service period compare very closely with the laboratory results and indicate that life expectancy of high silicon iron is excellent under all field conditions tested. Reports of over 50 installations received to date indicated good results. Several typical installations are cited.

High silicon iron anodes were substituted for aluminum in a water treating basin where the latter gave 18 months' service. One-inch anodes showed no measurable corrosion after a year's service and were expected to provide many times the service life obtained from aluminum. Current density was about 275 milliamperes per square foot.

No measurable weight loss was noted on four 1-inch high silicon iron anodes after two years' service protecting a fresh water standpipe at a compressor station. Previously used aluminum anodes gave less than two years' service at a 450 milliamperes per square foot current density. Based on initial results

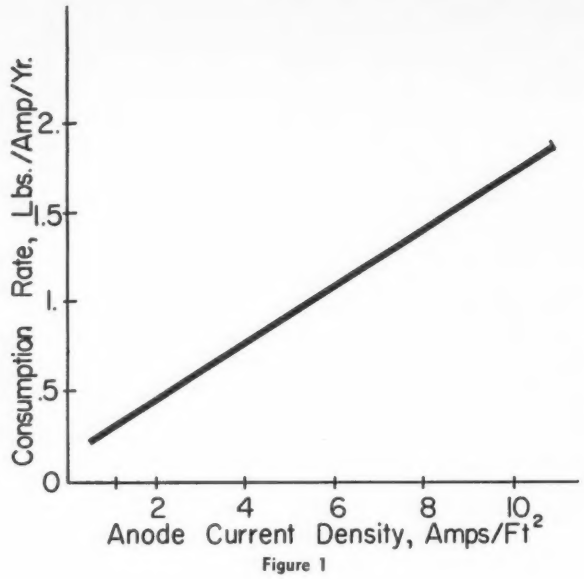

Figure 1

life expectancy of the high silicon iron anodes is in excess of 20 years.

A report was presented at the committee's 1955 annual meeting on a high silicon iron anode installation being evaluated in the water service tank of a large building in New York City where at that time high silicon iron was performing satisfactorily. It has been reported since that the original 2-inch anode was weighed and found to be corroding at a rate of 0.19-pound per ampere year. This rate is based on a two-year test. This 2-inch anode was one of the original anodes supplied in this experimental program and was used in parallel with a group of aluminum anodes to protect the tank. The high silicon iron anode continued to take an increasing proportion of the total current and after approximately one year, the aluminum anodes were replaced with a group of 1-inch high silicon iron anodes joined end-to-end to give the desired length. After approximately one year's service, five of these 1-inch anodes were weighed and the consumption rate calculated to be 0.16-pound per ampere year average. These figures check closely with those obtained in the laboratory and indicate a long service life with freedom from objectionable corrosion products. Current density in this installation is approximately 250 milliamperes per square foot.

High silicon anodes have been used at 750 milliamperes per square foot densities. A group of 1-inch x 60-inch anodes and a string of small anodes joined in tandem with lead wire for standpipe service were used to protect a 460,000-gallon city water tank and after 10,000 ampere hours no visible corrosion was noted. A total of 14 amperes was impressed at 17 volts, or about 750 milliamperes per square foot of anode surface.

Twenty 1-inch high silicon iron anodes have operated for approximately 350,000 ampere hours or the equivalent of 1½ years on a 100,000-gallon steel tank with very little corrosion noted. Current density of approximately one ampere per square foot was needed in this installation because water being handled was so treated for special boiler use that it produced no calcareous deposits to limit corrosion. Very slight anode corrosion was noted in this severe service whereas aluminum anodes required replacement every six months.

Temperature not Significant

Corrosion of high silicon iron does not vary within normal ranges of temperature. Anodes have operated satisfactorily at temperatures up to 200 F with no increased attack. This material is being installed currently in applications where temperatures of this magnitude are involved and results have been promising so far. Pasteurizing units, boiler water feed treating units, condensate return holding tanks, etc., are typical uses.

Protecting lead wires and the necessity of designing the installation to avoid lead wire immersion cannot be overemphasized. It must be pointed out also that the chlorine content of fresh waters is very important, especially at the higher temperatures. If composition of the water is such that chlorine gas can be generated at the anode surface, it becomes very destructive, especially at temperatures in excess of 150-160 F.

Sea Water

Information on laboratory testing of high silicon iron in synthetic sea water has been reported at several meetings of the committee. These tests showed relatively low consumption rates at current densities up to approximately 10 amperes per square foot as indicated in Table 2.

Tests in sea water conducted at the Kure Beach-Harbor Island Test Station, Wrightsville Beach, North Carolina, are also reported in this table.

Figure 1 was drawn from sea water data in Table 2.

Considerable interest has been shown in the use of high silicon iron in sea water and numerous trials have been made at a wide range of current densities. The most suitable current density to use depends upon the desired life of the installation. If a relatively large anode is used and a current density below three amperes per square foot selected, a life expectancy of 10 years appears definite. However, life varies in direct proportion to current density with expectancy diminishing as density increases. When the required life of an installation is not over three or four years a much higher current density can be tolerated on a large anode. The effect of heavy silt on anode life, when an anode is allowed to sink

TABLE 2—Laboratory Tests of High Silicon Cast Iron in Salt Water

Current Density Amp./Sq. Ft.	Consumption Rate, Lb./Amp. Year	
	Synthetic Sea Water	Sea Water[1]
0.5	Nil	1.0
1.0	0.25	0.42
3.0	0.32	0.74
5.0	0.53	0.84
6.5	....	1.02
7.0	....	1.47
7.5	0.85	....
8.0	....	1.71
10.0	0.90	2.42

[1] Kure Beach-Harbor Island Test Station. 79 days on 1½x12-inch anodes

freely, is variable so it is preferred that anodes be supported by ropes. If chlorine generated can dissipate readily, no difficulty will result, but when silt retards chlorine diffusion anode consumption increases. Many installations are being made taking these limitations into account.

It appears that when a high silicon iron alloyed with molybdenum is used the difficulty is reduced.

A report made previously to the committee on tests conducted with high silicon iron at Yonkers and New Rochelle, New York, indicated severe "necking" tendency on 2-inch anodes, but this tendency was greatly reduced by omitting radiator hose at the top which apparently served as a gas trap. It has been reported since that an anode which originally showed a 2.1 pound per ampere year consumption rate after 16,000 ampere hours at 7.7 amperes per square foot in 75 percent sea water dropped to 0.61 pounds per ampere year after about 100,000 ampere hours. This illustrates the tendency for corrosion to diminish with time. In sea water at 4.2 amperes per square foot a proportional consumption rate drop with time was obtained.

High silicon iron anodes alloyed with molybdenum also were tested in sea water service and showed a lower consumption rate than the high silicon iron anodes under equivalent conditions. Tests are continuing with both alloys using 3-inch diameter anodes designed to reduce difficulty at the lead connection. This work indicates the general suitability of these alloys for sea water service.

Cooler Box Installations

Several failures of high silicon iron have been noted in cooler boxes where they operated at 150 F and higher. At current densities normally used with high chloride-containing media like sea water or brackish water, considerable quantities of chlorine gas are generated at the anode surface and at temperatures near 150 F rapid attack results.

Based on a relatively small amount of field data, the critical temperature for high silicon iron alloy is in the range of 130-160 F with the exact temperature dependent on the volume of chlorine gas generated. In brackish waters having relatively small amounts of chlorine the maximum temperature may be 160 F while in sea water a temperature of 130 F is the maximum.

TABLE 3—Comparative Laboratory Tests of High Silicon Anodes With and Without Molybdenum
1.0 amp/sq ft Current Density, One Week

Temperature Degrees F	Consumption Rate, Lb./Amp. Year	
	High Silicon	Molybdenum Alloyed
Ambient	0.479	0.330
100	0.595	0.320
125	0.602	0.320
150	0.489	0.470
150	1.78	0.475
175	4.78	0.272
200	14.15	0.202

Comparative laboratory test results in synthetic sea water on high silicon iron anodes and anodes alloyed with molybdenum at various temperatures with a 1.0 ampere per square foot current density are given in Table 3.

The difference in the ambient temperature consumption rate in Table 3 for high silicon iron and that shown in Table 2 under like conditions is the result of different test periods. Rates from one week tests (Table 3) generally are higher than those from tests of longer duration (Table 2). Superiority of the high silicon iron alloy with molybdenum at higher temperatures is clearly demonstrated.

Service failure of high silicon iron anode at 175-200 F prompted evaluation of the molybdenum-alloyed iron. Duplicate test results were reported at 150 F to indicate the border-line resistance of high silicon iron at this level. The reason for the decreasing consumption rate for the molybdenum-containing alloy at the higher temperatures has not yet been determined. This alloy is now being evaluated in the field.

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The Use of Graphite As Duct Anodes*

By A. L. AYRES

Introduction

THE RETARDATION of underground lead sheathed cable corrosion may be accomplished by the application of cathodic protection. There are three generally accepted methods in the design of the associated anodes.

The first method, known as the point anode system, makes use of a large central anode bed. This is usually the most economical system to install. However, its use in many cases is unsatisfactory because of the difficulty in locating suitable anode sites and the susceptibility of other underground structures to interference currents from this source.

The second method, known as a distributed anode system, makes use of several small individual anodes installed adjacent to the conduit system at specified intervals. This method minimizes many of the interference problems, but the cost of installation in urban areas usually is excessive.

The third method, known as a duct anode system, consists of a sacrificial anode placed in a spare duct paralleling the cables to be protected. This method is ideal when the manhole sections requiring protection are few in number and are at scattered locations. The results of field tests indicate that interference with adjacent foreign underground structures with this system is practically nil. The operating life of such anodes is limited by the amount of sacrificial material that can be installed in the duct and the electro-chemical equivalent, pound per ampere year loss of the material.

The need for this third system has increased materially since the abandonment of many electrified railroads and trolley systems. Prior to this, proper bonding to sub-stations provided enough drainage current to alleviate or mask the effects of local corrosion cells and galvanic potentials.

Lead Anodes

Since 1937 the New Jersey Bell Telephone Company has been using lead as the anode material. The first anode consisted of AAA 5/8-inch lead water pipe with a No. 2 rubber covered wire in the core. The wire provided a means of pulling in the anodes and also served as the connection to the rectifier. Needless to say, with the loss rate of lead being approximately 75 pounds per ampere year, these anodes failed to last for any appreciable length of time. It also was discovered that these anodes had a tendency to separate as a result of the large dissipation of the metal at the duct joints.

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Abstract

A method of installing distributed graphite anodes in ducts paralleling power cable ducts is described, together with a variant of the method of installing them developed by the Bell System and National Carbon Company. Results of surveys of manhole sections in areas where telephone cables in Hoboken, N. J., were failing are given, together with the value of the cable sheath and proposed remedial measures. Cost of the protection is itemized. Tables are given showing estimated and actual anode current and service life. 5.2.3

Starting in 1942 these anodes were replaced with "Electrolysis Control Cable." This cable had a 6000-pound steel stranded wire for a core which was insulated from a half inch of lead extruded over it. The cable weighed approximately 7.5 pounds per foot, which was considerably more than the original water pipe. Observations made of installations utilizing this anode indicated that the tendency of large dissipation of metal still existed at the duct joints. It also was found that the salts formed at the point of decomposition anchored the "Control Cable" at the duct joints. This necessitated the moving of the anodes approximately six inches every six months.

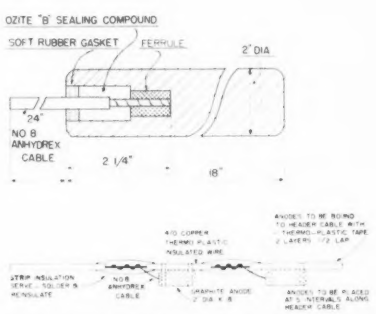

Figure 1—Philadelphia type graphite anode.

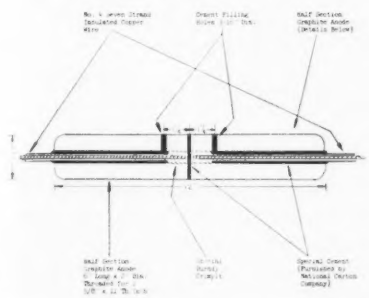

Figure 2—Graphite duct anode of the type manufactured by the National Carbon Company for the Bell System.

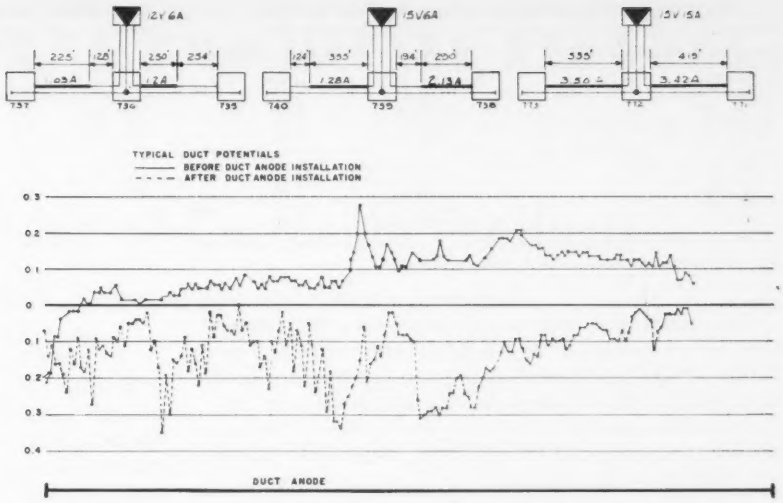

Figure 3—Schematic of protective system used on manholes sections listed in Table 1.

TABLE 1—Results of Duct Surveys

Location	Length of Subway (In Feet)	No. of Cables	Cable Sheath Footage	Value of Sheath	No. of Failures	Cost of Repairs	Potential in Duct (In Volts)	Current Loss to Slug (In Milli-amperes)	Proposed Remedial Measures	Cost of Protection System
Manhole 735-737 (2 Sections)	837	2	1674	$9,570.00	6 (From 1948-1953)	$1,800.00	—0.23 to +0.07	0 to 1.8	Place rectifier on pole opposite MH No. 736. Place duct anode extending 250 feet from MH No. 736 toward MH No. 735 operating at 1 ampere. Place duct anode extending 225 feet from MH No. 737 toward MH No. 736 operating at 1 ampere. (Duct anodes are placed in current loss areas).	$1,450.00
Manhole 738-740 (2 Sections)	943	3 for 738 to 739; 4 for 739 to 740	3298	$16,720.00	4 (From 1948-1953)	$3,900.00	—0.12 to 0.20	0 to 5.5	Place rectifier on pole opposite MH No. 739. Place duct anode extending 290 feet from MH No. 738 toward MH No. 739 operating at 2 amperes. Place duct anode extending 355 feet from MH No. 739 toward MH No. 740 operating at 2 amperes. (Duct anodes are placed in current loss areas).	$1,800.00
Manhole 771-773 (2 Sections)	948	8	7584	$34,691.00	7 (From 1949-1953)	$6,000.00	—0.10 to 0.38	0 to 10	Place rectifier on pole opposite MH No. 772. Place duct anode operating at 3 amperes between MH No. 771 and MH No. 772. Place duct anode operating at 10 amperes between MH No. 772 and MH No. 773.	$2,000.00

thus creating an additional maintenance problem and expense.

The Philadelphia Electric Anode

The Philadelphia Electric Company designed a duct anode consisting of small graphite rods spaced at intervals along an insulated header wire (See Figure 1). These graphite rods were 2 inches in diameter and 18 inches long and were equipped with a No. 8 rubber insulated copper wire lead or pigtail approximately two feet long. The header wire was a No. 4 stranded copper wire with thermoplastic insulation.

The duct anode was assembled by the Stuart Steel Protection Corporation in the following manner. The pigtails of the rods were served and soldered to the header wire at five-foot intervals. Each connection was insulated with a minimum of four layers of rubber insulating tape. A layer of thermoplastic tape covered the rubber tape.

Graphite was selected because of its low dissipation rate of 2.1 pounds per ampere year. The weight of a 2 inch diameter, 18 inch long graphite rod is approximately four pounds. The theoretical ampere capacity of such a rod is 1.9 ampere years. However, it is anticipated that the effective capacity will be approximately one half of this value.

No. 4 stranded copper wire was selected for the header wire on the basis of mechanical strength, high conductivity and flexibility. The average weight of the assembled anode is about one pound per foot. It was anticipated that the pulling tensions would be in the order of 1000 pounds per manhole section. The rated tensile strength of No. 4 stranded copper wire is 1200 pounds.

TABLE 2—Resistance Values at Two Manhole Locations

Manhole Section No.	Date	Resistance (Ohms)
735—736	9/28/54	64.00*
735—736	9/29/54	9.03
735—736	10/28/54	4.03
735—736	2/14/55	2.15
735—736	4/25/55	0.66
736—737	9/27/54	61.00*
736—737	9/28/54	8.00
736—737	10/28/54	4.30
736—737	2/14/55	3.83
736—737	4/25/55	2.27

* Measured immediately after installation of anode.

TABLE 3—Estimated and Actual Anode Currents

Manhole Section	Anode Length (Ft.)	No. of Rods	Estimated Current (Amps.)	Actual Current (Amps.)	Ma Per Rod	Estimated Life (Years)
735—736	250	50	1.0	1.7	34.0	29.4
736—737	225	45	1.0	1.4	31.1	32.2
738—739	290	58	2.0	2.2	37.9	26.4
739—740	355	71	2.0	1.3	18.3	54.6
771—772	419	82	3.0	2.9	35.4	28.2
772—773	535	103	10.0	5.4	52.5	19.1

The individual rods were secured to the header wire by wrappings of 20 mil thick thermoplastic tape. These wrappings started about two inches from each end of the rod and extended for approximately two inches. This served a dual purpose: it eliminated any tension on the pigtail connection, and it facilitated the placing of the anode.

The Bell System has installed some of the Philadelphia Electric anodes. The installations discussed later utilized this type of anode.

The Bell System Anode

Problems arose which caused the Bell System and National Carbon Company to develop a different type of graphite rod to be used as a duct anode. (See Figure 2.) It was decided that the two inch diameter was suitable, provided that the header wire passed through the rod instead of being adjacent to it. The reason for this was the telephone ducts are 3-inch ducts in comparison to the 4-inch power ducts. It also was determined that the anode would have to be reduced in length to 12 inches in order to make it adaptable for placing in the bends experienced in some telephone ducts.

The Bell System anode is a graphite rod 2 inches in diameter and 12 inches long. It has a hole drilled through the center which is slightly larger than the diameter of a No. 4 seven strand copper wire with insulation similar to Simplex Anhydrex. The rod is cut in half and the center of each half is threaded for one inch for a $\frac{5}{8}$ inch 11 threads per inch special "Burndy Crimpit." Each half of the rod is provided with compound filling holes $\frac{3}{16}$ inch in diameter located $1\frac{1}{4}$ inches from the center end.

The assembly of the anode is accomplished in the following manner:

1. Each half is placed on the wire with the centers facing. (Several may be strung at once if so desired.)
2. The wire is cut at the point of the center of the rod location.
3. The ends of the wire are cleaned, placed in the special crimpit and crimped.
4. The center faces of the two halves are painted with a special cement provided by the National Carbon Company.
5. The two halves are then screwed together, the cement forming a perfect seal.
6. A compound is forced in the compound filling holes by means of a tool similar to a caulking gun. This forcing is continued until the compound appears at the far end of each half, thereby ensuring a moisture proof seal.

Tensile strength tests have been made of this assembly and the No. 4 wire breaks before damaging the assembly. It is believed that this type of connection will be less susceptible to moisture deterioration than a taped splice.

New Jersey Bell Installations

The underground telephone cable plant in Hoboken, New Jersey, presented a comparable problem to that of the Philadelphia Electric Company. A detailed study of the cable sheath corrosion failures in the Hoboken area indicated that six manhole sections were the main offenders. As a result duct surveys were made in these six sections.

A standard "Bell System" slug was used in making the measurements. The slug was constructed by placing a 16-inch piece of 2-inch inside diameter lead-antimony sleeving over a duct rod. An insulated wire was soldered to the inside of the sleeve, and the ends were "beat in." The slug was then filled with No. 1 Pressure Plug Asphalt. The purpose of the filling was to provide a moisture seal for the connection and additional weight to the slug. It has been determined from experience that when current losses to this slug exceed 0.5 milliamperes, the cable sheath in all probability is corroding.

Table 1 gives the history of failures, the results of the duct surveys, and the proposed remedial measures. A schematic of the protective system can be found in Figure 3.

The installations listed in Table 1 were completed by November of 1954. One of the interesting factors was the decrease in resistance of the anodes after installation.

Table 2 gives the values for two of the six manhole locations.

Table 3 shows a comparison between the estimated anode current and the actual current. It also indicates the anticipated life of the anodes based on one ampere year per rod and assuming uniform distribution of current among the individual rods.

Recent duct surveys indicate that with the existing current values the potentials range from —0.15 volt to —0.50 volt. It is anticipated that in the near future the current values can be reduced. This is indicated by the fact that the potential values are more negative than indicated by previous surveys. Therefore, the life of the anodes may be extended beyond the forecast.

Publication 57-5

Section One

Bibliographies of Corrosion Products

By NACE Technical Unit Committee T-3B on Corrosion Products*

Introduction

BIBLIOGRAPHIES in this section were prepared by Technical Unit Committee T-3B on Corrosion Products. This work is an introductory reference to the subject of "corrosion products" and is not intended to be exhaustively complete. Selected key references and some others of particular interest are given, omitting many which probably might well have been included. Some of those omitted will be added to proposed future bibliographies.

All members of Committee T-3B contributed. E. L. Simons assisted in coordinating work of the contributors and M. C. Bloom, E. L. Simons, H. P. Godard, N. A. Nielsen and R. T. Foley edited the material.

A. H. Roebuck, Continental Oil Co., Ponca City, Okla., chairman.

Abstract

Selected abstracts arranged chronologically with most recent abstracts first are included on the identification and composition of corrosion products on stainless steels, zinc, zirconium, titanium and iron and steel. Included are 43 abstracts on stainless steels; 13 on zinc; 7 on zirconium; 8 on titanium; 130 on iron and steel. The last category includes an alphabetical author list. 3.4.3

Part 1—STAINLESS STEELS*

Corrosion Products

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* Prepared by N. A. Nielsen and T. N. Rhodin, E. I. duPont de Nemours & Co., Inc.

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The Nature of Passivity in Stainless Steels and Other Alloys. H. H. UHLIG AND J. WULFF. *Am. Inst. Mining Met. Engrs.*, Iron and Steel Div. Metals Technol., **6,** T. P. 1050 (1939); T. P. 1121 (1939). In presenting their theory of passivity the authors claim that a study of the corrosion products of stainless steel indicates that the surfaces of the alloy have the same composition as the bulk alloy.

The Use of Electron Diffraction in Studying Corrosion. I. R. LANDAU. *Metals and Alloys,* **9,** No. 3, 73-77 (1938); **9,** No. 4, 100-103 (1938). The technique of electron diffraction, its advantages and limitations are discussed. Results of electron diffraction studies of surface films on aluminum, iron and stainless steel are presented.

Behavior of Rustless Steel Toward Corrosion. W. PALMAER. *Korrosion u. Metallschutz,* **10,** 181-90 (1934). Corrosion phenomena occurring in 5 N HCl were studied in terms of specimen weight loss, hydrogen evolution, corrosion products in solution and oxide film formation. (*C. A.*, **28,** 6687[9], (1934)).

Thin Surface Films on Metals. L. TRONSTAD. *Trans. Faraday Soc.*, **29,** 502-514, 1933. By use of variation in the angle of reflection of polarized light from metal surfaces Tronstad claims to have detected a 30 Å. thick oxide film on 18-8 stainless steel.

Part 2—ZINC*

Corrosion Products

The Atmospheric Corrosion of Rolled Zinc. E. A. ANDERSON. Symposium on Atmospheric Corrosion, ASTM, June 1955. Normal atmospheric corrosion product on zinc stated to be the basic carbonate. Some basic zinc sulfate may be present in industrial environments.

The Nature of Zinc Corrosion Products. P. T. GILBERT. *J. Electrochem. Soc.*, **99,** 16-21 (1952). Seven corrosion products are produced experimentally in CO_2-free distilled water. Only two, ZnO and $Zn(OH)_2$ could be identified. Diffraction data for other forms are given.

Der Einfluss Stofflich—Chemischer Faktoren auf die Korrosion der Metalle. W. FEITKNECHT. *Schweizer Archiv Angew. Wiss und Tech.* **18,** 368379 (1952). Corrosion products produced by local cell

* Prepared by E. A. Anderson, New Jersey Zinc Co. of Pennsylvania.

action in chloride solutions include ZnO, $Zn(OH)_2$ and $ZnCl_2 \cdot 4\ Zn(OH)_2$.

Uber den Zusammenbruch der Oxydfilme auf Metallober flächen in sauren Dämpfen und den Mechanisms der Atmosphärischen Korrosion. W. Feitknecht. *Chimia* (Switz), **6**, 3-13 (1952). In the presence of low concentrations of HCl vapor $ZnCl_2 \cdot 4Zn\ (OH)_2 \cdot H_2O$ forms. Soluble zinc chloride forms at higher concentrations.

Pitting of Zinc by Distilled Water and Dilute Solutions. U. Evans and D. E. Davies. *J. Chem. Soc.*, Part 3, 2607-2614 1951). White corrosion product around pits produced in distilled water identified as $Zn(OH)_2$. Interference color film under white film was oriented, anhydrous ZnO. Randomly oriented ZnO found on unexposed, as-rolled zinc.

"White Rust" Formation on Zinc. P. T. Gilbert and S. E. Hadden. *J. Inst. Met.*, **78**, 47-50 (1950-51). "White Rust" produced experimentally consisted of ZnO and $2\ ZnCO_3 \cdot 3\ Zn(OH)_2$ but amorphous $Zn(OH)_2$ may be present undetected. HCl vapor formed zinc oxychloride possibly by later reaction between primary ZnO and $ZnCl_2 \cdot 4\ Zn(OH)_2 \cdot H_2O$.

Über die Lőschkeitsprodukte einiger Hydroxyverbindungen des Zinks. W. Feitknecht and E. Haberli. *Helvetia Chim. Acta*, **33**, 922-936 (1950). Potential corrosion products of zinc were studied by alkali precipitation from zinc nitrate and chloride solutions. Basic nitrates and chlorides were identified.

Corrosion Products on Zinc Anodes Underground. E. A. Anderson. *Corrosion*, **6**, 129-131 (1950). Corrosion products on zinc anodes in soil usually are the basic carbonate. When high concentration of sulfates is present in soil basic zinc sulfate forms.

The Corrosion of Metals in Air. W. H. G. Vernon. *Chem. & Ind.*, **62**, 314-318 (1943). Zinc oxide produced by heating zinc in air contains an excess of zinc ions. Rate of oxidation varies logarithmically with time.

Electron Diffraction and Corrosion Products of Zinc. Shigeto Yamaguchi. *Sci. Papers Inst. Phys. Chem. Research* (Tokyo), **40**, 157-162 (1942). Products of corrosion of zinc in dilute aqueous solutions of HCl, HBr and HI were identified as $ZnCl_2$, $ZnBr_2$ and ZnI respectively. (*C. A.* **41**, 5842i (1947)).

X-ray Analysis of Corrosion Products from Galvanized Sheets. F. R. Morral. *Trans. Electrochem. Soc.*, **77**, 279-286 (1940). Corrosion products from galvanized sheet exposed variously to moisture included ZnO, $ZnCO_3$, $2\ ZnCO_3 \cdot 3\ Zn(OH)_2$ and possibly other basic salts.

Corrosion of Zinc. E. A. Anderson and M. L. Fuller. *Metals and Alloys*, **10**, 282-286 (1939). Zinc corroded in CO_2-free distilled water formed ZnO or, probably, $Zn(OH)_2$. X-ray and electron diffraction studies showed that in presence of CO_2, ZnO formed first later converting to $4\ ZnO \cdot CO_2 \cdot 4H_2O$.

Effect of Temperature on the Corrosion of Zinc. G. L. Cox. *Ind. Eng. Chem.*, **23**, 902-904 (1931). Changes in physical appearance of corrosion products of zinc in aerated distilled water with temperature were followed. Products were gelatinous at room temperature and granular at elevated temperatures.

Part 3—ZIRCONIUM*
Corrosion Products

Behavior of Titanium, Vanadium and Zirconium in Fusion Agents. R. S. Young and K. G. A. Strachen. *Chem. and Ind.* 154-155 (1953).

Effect of NaHSO4, Na_2CO_3, NaOH and Na_2O_2.

Action of Hot Ionized Gases on Zirconium and Copper. A. Dravnieks. *J. Phys. and Colloid Chem.*, **55**, 540-549 (1951). *Chemical Abstracts*, **45**, 6021[h].

Reaction at 986 degrees between metal and O_2, air, H_2O, N plus 0.5% O_2, comm. He, CO_2, CO and C_2H_4. Effect of ionization of the gas is discussed.

Effects of Heating Zirconium In Air, Oxygen and Nitrogen. E. T. Hayes and A. H. Robertson. *J. Electrochem. Soc.*, **96**, 142-151 (1949). *Chemical Abstracts* **43**, 8910[f].

Observations on gain in weight, micro and macro-hardness and metallographic structures from 425 to 1300 degrees. Hard-surface coatings are discussed.

Reactions of Zirconium, Titanium, Columbium and Tantalum with the Gases Oxygen, Nitrogen and Hydrogen at Elevated Temperatures. E. A. Gulbransen and K. F. Andrew. *J. Electrochem. Soc.*, **96**, 364-376 (1949). *Chemical Abstracts* **44**, 961[b].

Study of time, temperature, and pressure variables. Surface structure studied by electron diffraction. Diffusion constants and energies of activation are calculated.

Kinetics of the Reactions of Zirconium, Oxygen, Nitrogen and Hydrogen. E. A. Gulbransen and K. F. Andrew. *J. Metals*, **1**, No. 8, Trans 515-526 (1949) *Chemical Abstracts* **43**, 8817[b].

Study of kinetics as a function of time, temperature, pressure surface preparation, and stability of the particular film. No evidence of an unstable oxide. Nitride stable to at least 900 degrees. No hydride film is formed.

Oxide Films Formed on Titanium, Zirconium and Their Alloys with Nickel, Copper and Cobalt. J. W. Hickman and E. A. Gulbransen. *Anal Chem.*, **20**, 158-165 (1948) *Chemical Abstracts*, **42**, 2906[e].

Studies by electron diffraction. In the range 300-700 degrees Zr yields ZrO_2, 20 Zr-Cu alloy—CuO and Cu_2O; 60 Zr-Co alloy—Co_3O_4; 70 Zr-Ni alloy—NiO.

Reactions of Zirconium with Gases at Low Pressure. W. G. Guldner and L. A. Wooten. *J. Electrochem. Soc.*, **93**, 223-234 (1948) *Chemical Abstracts*, **42**, 5366[b].

Products of the reactions of zirconium with oxygen, nitrogen, carbon dioxide, carbon monoxide and water vapor were studied by means of electron and X-ray diffraction analysis. Zirconium reacted with carbon monoxide or carbon dioxide at 600-800 degrees yields ZrO_2 and ZrC.

* Prepared by D. A. Vaughn, Battelle Memorial Institute.

Part 4—TITANIUM*
Corrosion Products

Charging Processes on Anodic Polarization of Titanium. Colby D. Hall, Jr. and Norman Hackerman. *J. Phys. Chem.*, **57**, 262-8 (1953).

The anodic treatment of Ti in neutral NaCl solutions produces a film of TiO_2. (*C.A.* **47**, 6274b).

Participation of Nitrogen in the High-Temperature Oxidation of Titanium in Air. V. I. Arkharov and G. P. Luchkin. *Doklady Akad. Nauk SSSR*, **83**, 837-9 (1952).

By X-ray examination, the scale formed by oxidation is in all cases rutile, TiO_2, with some TiO in the thin inner layer close to the metal. At 1100 to 1200C, some Ti_2O_3 appeared in a middle layer. (*C. A.*, **46**, 8559h).

Scaling of Titanium at High Temperatures. P. H. Morton and W. M. Baldwin, Jr., *Iron Age*, **169**, No. 18, 133-8 (1952).

At 850 to 1000C, a transition from a primary light scale to a black scale was observed. The black scale nucleated at relatively few points and was accompanied by a change to a higher scaling rate. Layers of TiO and TiO_2 were identified. (*CA*, **46**, 7015b).

The Isolation and Examination of Films from Metal Surfaces: An Improved Technique. T. J. Nurse and F. Wormwell. *J. Appl. Chem.*, (London) **2**, 550-4 (1952); cf. *C. A.* **33**, 5786-3; **39**, 5234-2.

Films were stripped in an anhyd. deaerated soln. of I in alc. The oxides from Ti and other metals were examined. (*C. A.* **47**, 1018i).

Oxidation of Titanium. M. H. Davies and C. E. Birchenall. *J. Metals*, **3**, 877-80 (1951).

Tracer expts. indicate that O diffuses in at least one phase of the scale. (*C. A.* **45**, 10161b).

Preparation, Structure and Applications of Thin Films of Silicon Monoxide and Titanium Dioxide. Georg Hass. *J. Am. Ceram. Soc.*, **33**, 353-60 (1950).

Films of TiO_2 (rutile) were prepared by evapg. Ti and oxidizing it in air at 400-450. (*C. A.* **45**, 1403d).

Reactions of Zirconium, Titanium, Columbium and Tantalum With the Gases, Oxygen, Nitrogen and Hydrogen at Elevated Temperatures. Earl A. Gulbransen and Kenneth F. Andrew. *J. Electrochem. Soc.*, **96**, 364-76 (1949).

Surface structures were studied by electron diffraction. (*C. A.* **44**, 961b).

Gmelins Handbuch der Anorganischen Chemie 8th Edition, System Number 41. Titan. Verlag Chemie GmbH, Weinheim/Bergstrasses 1951.

(Literature survey complete to the end of December, 1949).

Pages 189 to 199: Chemical Properties of the Metal—Reactions with air and upon heating; with water, HF, HCl, H_2SO_4, HNO_3, various acids and alkalis. Reactions with non-metals—Argon, hydrogen, oxygen, nitrogen, halogens, sulfur, selenium and tellurium, boron, car-

* Prepared by Robert D. Misch, Argonne National Laboratories.

bon, silicon, and phosphorus. Reactions with non-metallic compounds—ammonia, gaseous hydrogen halides, various non-metal compounds. Reactions with Metal Compounds—oxides, nitrates, hypochlorites, chlorates, persulfates and permanganates; sulfides and sulfates, nitrides and amides, halides, carbonates, acetates. Reaction with organic compounds.

In addition, references are given to the following: Page 231, oxide films; Page 272, nitride films.

Part 5—IRON and STEEL*

Corrosion Products

1. Corrosion of Steel in Boilers—Attack by Dissolved Oxygen. H. A. Grabowski. *Trans. Am. Soc. Mech. Engrs.*, **77,** 433-448 (1955).

Microscopic and metallographic techniques were employed to examine some problems in boiler corrosion.

2. Adhesion as a Function of the Interface. A. E. Austin and B. G. Brand. *Div. of Paint Plastics Printing Ink Chem.*, Preprint, **15,** No. 1, 1-7 (1955).

The effect of various pre-treatments and of accelerated weathering on the adhesion of organic coatings to Fe, Al, and Mg alloys was investigated. Hydrous oxides of the respective metals were identified as the products of oxidation and hydrolysis at the metal-to-coating interface. Electron diffraction techniques were employed.

3. Electron Diffraction Determination of the Composition of the Oxide Film Formed on the Surface of Iron. J. Moreau and J. Bardolle. *Compt. Rend,* **240,** 524-526 (1955).

Reflection and transmission diffraction patterns were made of the surfaces of iron specimens which had been oxidized in the range 250 to 700 C. Above 600 C, FeO, Fe_3O_4 and α-Fe_2O_3 coexist in the scale. Between 250 and 550 C a spinel phase coexists with α-Fe_2O_3. Certain lines present in the pattern of the oxide formed at 250 C may be attributed to γ-Fe_2O_3; these lines are not present above 250 C, a temperature above which γ-Fe_2O_3 is unstable.

4. Gases in Metals. N. Christensen. *Teknisk Ukeblad,* **101,** 693-703 (1954).

The effect of oxygen, nitrogen and hydrogen on the properties of iron and steel are discussed. Methods for detecting these gases are described. The American and German literature are reviewed. (*Metals Rev.*, **27,** 1061-Q (1954).)

5. Nickel in Iron and Steel. A. M. Hall. Chapter 9, John Wiley and Sons, Inc., New York, 1954.

The effect of environment and composition on the corrosion of nickel steels is discussed. Weight loss was employed as a measure of corrosion. The composition of scales on various nickel steels is given.

6. Fretting Corrosion of Mild Steel in Air and in Nitrogen. I-Ming Feng and H. H. Uhlig. *J. Appl. Mechanics,* **21,** 395-399 (1954).

The effect of humidity, duration of operation, temperature, pressure and frequency of fretting damage to mild steel was examined. The major constituent of the corrosion products formed in tests at —140 C, +157 C, and at room temperature was α-Fe_2O_3 as determined by x-ray diffraction. The extent of damage resulting from fretting corrosion is much less in moist air than in dry air and at temperatures up to 150 C, than at lower-than-room temperatures.

7. The Oxidation of Iron at 175 to 350 C. D. E. Davies, U. R. Evans and J. N. Agar. *Proc. Roy. Soc.*, London, **A225,** 443-462 (1954).

Hydrogen-reduced iron sheet and iron powder were oxidized; the oxidation products were examined by gravimetric, electrometric and diffraction methods. Magnetite was present on iron specimens exposed to air at room temperature. A mixture of iron oxides forms on the surface of iron powder even at 40 C. Between 175 and 225 C α Fe_2O_3 is formed on sheet iron while at temperatures up to 350 C a magnetite layer (not γ-Fe_2O_3) is overlaid with an α-Fe_2O_3 layer.

8. Electron Optical Study of Oxidation of High Purity Iron at Low Oxygen Pressures. E. A. Gulbransen, W. R. McMillan and K. F. Andrew. *J. Metals,* **6,** 1027-1035 (1954).

The mechanism of oxide growth on pure iron at temperatures between 650 and 850 C was investigated by a study of the crystal habit and structure of the oxide film. Electron diffraction, electron microscopy, weight gain, color and film thickness studies were made. A thin layer of oxide crystallites form on the metal surface at the initiation of oxidation. The original crystals grow and other crystals form in the vacancies at the surface as oxidation proceeds.

9. Oxide Film Composition Studies. T. N. Rhodin. *Ann. N.Y. Acad. Sci.,* **58** (Part 6), 855-872 (1954).

Films were removed from stainless steels and related alloys by the use of either "Mylar" tape or a bromine-methanol solution. Both x-ray fluorescence and micro-chemical analysis techniques were developed for this study. Surface films on stainless alloys are not necessarily enriched by the elements Cr, Ni and Mo which are usually associated with passivity; instead there is marked silica enrichment.

10. An Investigation of Intergranular Oxidation in Stainless Steel. C. A. Siebert, M. J. Sinnott and R. E. Keith. University of Michigan, 125 pp., September, 1954. (WADC Technical Report 54-120) (Contract No. AF 33(616)-353).

Specimens of 310 stainless steel which had been oxidized in dry, moving air between 1000 and 2000 F were examined microscopically to determine the severity of intergranular oxidation. The scales from these specimens were analyzed by x-ray and magnetic methods and were found to contain Cr_2O_3, Cr_2O_3-Fe_2O_3 solid solutions, Fe_2O_3 and a spinel phase. All scales examined were protective in nature.

11. Corrosion of Reactor Structural Materials in High-Temperature Water. I. Descaling Methods. R. Fowler, D. L. Douglas and F. C. Zyzes. 26 pp., Schenectady, Aug. 27, 1954. (Knolls Atomic Power Laboratory, KAPL-1198) (Contract No. W-31-109 Eng. 52).

A quantitative determination of the extent of corrosion can be made following the use of a descalant. Descaling techniques useful in the removal of high temperature water scales from mild and stainless steels are described and evaluated.

12. Investigations of the Oxidation of Chromium and Nickel-Chromium Steels, H. J. Yearian. 91 pp., Lafayette, Indiana, June, 1954. (Purdue University, N7Onr-39419).

The scales on various steels which had been oxidized between 700 and 1100 C were characterized by diffraction techniques, microscopy and chemical analyses. The composition and structure of the scale depended on the conditions of oxidation and on the composition of the alloy. Mild oxidation produced relatively thinner films comprised of rhombohedral Fe_2O_3 and Cr_2O_3 oxides. More vigorous oxidation produced thick scales containing Fe-Cr-Ni spinels.

13. Analysis of Water-Formed Deposits. F. U. Neat and A. A. Berk. *Ind. Eng. Chem.,* **46,** 961-970 (1954).

A detailed scheme for the quantitative analysis of the water-formed deposits in a boiler plant is presented.

14. The Protective Action of Pigments on Steel, M. J. Pryor. *J. Electrochem. Soc.,* **101,** 141-148 (1954).

The effect on the corrosion of mild steel of aqueous extracts from litharge, metallic lead, red lead, basic lead carbonate, zinc and zinc oxide was investigated. Chemical and electron diffraction analysis indicated that γ-Fe_2O_3 comprised the passive film formed in litharge extracts; neither hydrated iron compounds nor lead compounds were in the film. Only the extracts from litharge gave prolonged inhibitive action.

15. Adsorption Studies on Metals. III. The Sorption of Water Vapor on Nickel, Steel and Molybdenum. A. C. Zettlemoyer and J. J. Chessick. *J. Phys. Chem.,* **58,** 242-245 (1954).

Nickel and 1021 steel powders activated at 25 C and nickel activated at 25 C and nickel activated at 400 C physically adsorbed argon and water vapor. Molybdenum activated at 25 C and at 400 C and steel activated at 400 C adsorbed water vapor probably by a mechanism in which water molecules diffuse through the external porous oxide layer.

16. The Mechanism of Inhibition of the Corrosion of Iron by Solutions of Sodium Phosphate, Borate and Carbonate. J. E. O. Mayne and J. W. Menter. *J. Chem. Soc.,* **1954,** 103-107.

Electron diffraction and chemical analysis were used to characterize oxide films formed on iron in 0.1 N sodium hydroxide solutions containing various inhibitors. The primary constituent of all the films was a cubic oxide—either Fe_3O_4 or γ-Fe_2O_3. In disodium hydrogen phosphate large particles of $FePO_4 \cdot 2H_2O$ also formed in the film.

17. The Mechanism of Inhibition of the Corrosion of Iron by Sodium Hydroxide Solution. Part II. J. E. O. Mayne and J. W. Menter. *J. Chem. Soc.,* **1954,** 99-103.

Anodic polarization studies and observations made by electron diffraction indicate that Fe_3O_4 or γ-Fe_2O_3 comprise the film formed on iron surfaces following exposure to 0.1 N NaOH solution. Air-formed films have the same composition. Dissolved O_2 accelerates passivation by NaOH solution.

* Prepared by M. J. Boehm and M. C. Bloom, Naval Research Laboratory.

18. Surface Studies With the Vacuum Microbalance: Instrumentation and Low-Temperature Applications. T. N. Rhodin. Advances in Catalysis, Vol. 5, Academic Press Inc., New York, 1953. pp. 39-117.

Applications and instrumentation in connection with the vacuum micro-balance are exhaustively treated. Particular attention is given to the use of microgravimetric methods for low-temperature investigations.

19. Surface Studies with the Vacuum Microbalance: High-Temperature Reactions. E. A. Gulbransen. Advances in Catalysis, Vol. 5, Academic Press Inc., New York, 1953. pp. 119-175.

Application of the vacuum microbalance to various problems is reviewed. Section IV is devoted to studies of oxidation of metals.

20. An Investigation of Accelerated Oxidation of Heat Resistant Metals Due to Vanadium. F. C. Monkman and N. J. Grant. *Corrosion*, **9**, 460-466 (1953).

Oxidation rates for 316 stainless steel were determined in synthetic melts of fuel ash constituents. Type 347 steel was reacted with melts of V_2O_5, V_2O_5 and $FeVO_4$ and of Fe_2O_3 and $FeVO_4$. Chemical analysis and x-ray diffraction examination of the reaction products indicate that molten V_2O_5 is responsible for the acceleration of high temperature oxidation.

21. Corrosion of Steel in Dilute Solutions of Sodium Salts of Weak Acids. M. J. Pryor. *Corrosion*, **9**, 467-477 (1953). Chemical analysis, x-ray diffraction, and metallographic techniques were used to characterize the corrosion products. Polarization studies showed that corrosion products of high permeability and low electrical resistance (such as γ-FeOOH) permitted general attack while films of low permeability and high resistivity (such as α-FeOOH or $Fe_3(PO_4)_2$-$8H_2O$) inhibited attack.

22. Solubility of the Products of Corrosion of Stainless Steel in 600 F Water. H. A. Pray and E. F. Stephan. 12 pp. Columbus, Ohio, Nov. 30, 1953. (Battelle Memorial Institute, BMI-891) (Contract No. W-7405-eng-92).

The solubility of the corrosion products of Type 347 stainless steel and of analytical grade iron were determined at room temperature and at 600 F. Spectrophotometric methods of analysis showed that no more than 0.03 ppm. of Fe, Ni, or Cr were in solution following corrosion. Magnetic iron oxide was in the sediment at the bottom of the test autoclaves.

23. Contact Corrosion of Stainless Steels in Water at Temperatures up to 600 F. H. A. Pray and C. W. Berry. 24 pp., Columbus, Ohio, Nov. 24, 1953. (Battelle Memorial Institute, BMI-886) (Contract No. W-7405-eng-92).

X-ray analyses show that the film which forms on 410 stainless in degassed or in hydrogen-containing water consists of a spinel oxide. The film formed upon exposure to oxygen-containing water is comprised of an interior layer of spinel over which is a layer of α-Fe_2O_3.

24. A Study of the Oxidation of High Purity Iron and the Mechanism of the Decomposition of the "Wustite Phase." R. Collongues, R. Sifferlen and G. Chaudron. *Rev. met.*, **50**, 727-735 (1953).

The oxidation of pure iron in H_2-H_2O mixtures in the temperature range 350 to 850 C was studied. A plot is included which shows the variation in the crystal parameter (measured by x-ray diffraction) of the surface oxide with distance from the metal-oxide interface. Metallographic examination indicated that a compact external layer overlays a fine-grained internal layer. The scale was thicker on ferrous alloys containing Cu, Co and Mn than on pure iron.

25. Some Notes on the Oxidation Resistance of Boron-Containing Chromium-Nickel-Cobalt-Iron Alloys. W. O. Binder and E. D. Weisert. *Corrosion*, **9**, 329-332 (1953).

At temperatures above 1650 F boron inhibited the formation of protective Cr_2O_3 scales unless the iron content of the alloy was kept below 6 percent. X-ray diffraction was employed to determine the composition of scale formed on various alloys by high temperature oxidation. Weight loss measurements were employed to determine the extent of oxidation.

26. Corrosion of Steel by Air-Free, Dilute, Weak Acids. N. Hackerman and E. E. Glenn. *J. Electrochem. Soc.*, **100**, 339-344 (1953).

A spray of dilute (500 to 100 ppm) acetic acid solution did not attack mild steel appreciably in the absence of air or CO_2. The attack was accelerated by the presence of Co_2 at 1.5 atmospheres' partial pressure; under these conditions the corrosion product was $FeCO_3$ as identified by x-ray diffraction.

27. Progress in Metallurgical Microscopy. B. W. Mott. *Endeavour*, **12**, 154-161 (1953).

A general review of some recent advances in the study of surface topography is given. The use of phase microscopy, polarized light and vacuum heating stages is discussed.

28. Self-Diffusion of Iron in Iron Oxides and The Wagner Theory of Oxidation. L. Himmel, R. F. Mehl and C. E. Birchenall. *J. Metals*, **5**, 827-844 (1953).

The rate at which iron diffuses inward through the magnetite layer. The transference number of Fe(II) ions at 1000 C is 2×10^{-4}.

29. Identification of the Precipitate Accompanying 885 F Embrittlement in Chromium Steels. R. M. Fisher, E. J. Dulis and K. G. Carroll. *J. Metals*, **5**, 690-695 (1953).

Electron and x-ray diffraction, magnetic measurements and x-ray fluorescence analyses were used in characterizing the precipitate which formed during 885 F embrittlement of chromium steels. The precipitate contained as much as 94 percent chromium in some cases.

30. The Solubility Product of Ferrous Hydroxide and the Ionization of the Aquo-Ferrous Ion. D. L. Leussing and I. M. Kolthoff. *J. Am. Chem. Soc.*, **75**, 2476-2479 (1953).

The solubility products

$$S_{1\,Fe(OH)_2} = a_{FeOH^+} \times a_{OH^-}$$

and

$$S_{2\,Fe(OH)_2} = a_{Fe^{++}} \times a^2_{OH^-}$$

were found to be 4×10^{-10} and $8 \pm 3 \times 10^{-16}$ respectively at 25 C. The pH of hydroxide suspensions was measured. The concentration of Fe (II) ion was determined by titration with ceric sulfate. Evidence of the existence of a soluble ammino-iron (II) complex was obtained.

31. The Inhibition of the Corrosion of Iron by Some Anodic Inhibitors. M. J. Pryor and M. Cohen. *J. Electrochem. Soc.*, **100**, 203-215 (1953).

X-ray examination was employed to determine the corrosion products of iron in various solutions of anodic inhibitors. Iron was passive in 0.1 N solutions of sodium acetate, benzoate, carbonate, hydroxide, orthophosphate and silicate in the presence of air. Deaerated solutions of sodium chromate, nitrate, tungstate and molybdate passivated iron.

32. The Magnetic Susceptibilities of Pure and Slightly Oxidized Ferrous Hydroxide. J. Zernikea and B. C. Sinha. *Rec. Trav. Chim.*, **72**, 390-394 (1953).

A method for preparing white $Fe(OH)_2$ is described. The magnetic susceptibility at 28.4 C is $\kappa = 11{,}200 \times 10^{-6}$ c.g.s. units per mole at 28.4 C. The hydroxide samples were analyzed by titration with permanganate.

33. Structure of Iron Oxides Formed in Boiler Deposits of Thermoelectric Plants. A. N. Khlapova. *Izvest. Akad. Nauk. SSSR*, Ser. Fiz., **17**, 186-194 (1953). Chemical and x-ray analyses made on boiler scales showed that the scale was primarily iron oxide. Both electrochemical and oxidation corrosion mechanisms are described (*C. A.*, **47**, 11611g (1953).

34. An Electron-Micrograph Study of Oxide Films on Electropolished Surfaces of Iron. E. J. Caule and M. Cohen. *Can. J. Chem.*, **31**, 237-241 (1953).

An electropolishing technique for iron is described. Electron microscopical examination showed that an oxide film existed on the electropolished surface.

35. The Oxidation of Iron Around 200 C. W. H. J Vernon, E. A. Calnan, C. J. B. Clews and T. J. Nurse. *Proc. Roy. Soc.*, **A216**, 375-397 (1953).

The mechanism of the oxidation of mild sheet steel in the vicinity of 200 C was investigated by gravimetric, microchemical and electron diffraction techniques. Below 200 C oxygen ion diffusion is responsible for oxide growth while above 200 C metal ion diffusion predominates. Evidence is given to show that γ-Fe_2O_3 initially present in the film transforms after a time to Fe_3O_4; the transformation is much more rapid at temperatures above 225 C.

36. 'Stalactite' Formation in a Boiler. C. H. Greener. *J. Appl. Chem.*, **3**, 84-85 (1953).

The growth of hollow projections of corrosion product on the sides and tops of steam-boiler tubes was examined. X-ray diffraction data showed that adjacent to the metal was a spinel iron oxide on which had grown α-Fe_2O_3. A white deposit of apatite from the boiler water covered the oxide scale.

37. The Oxidation of Ferrous Hydroxide. I. E. O. Mayne. *J. Chem. Soc.*, **1953**, 129-132.

In the pH range 4 to 5 and at room temperature γ-FeOOH is the oxidation

product. At pH > 5 α-FeOOH forms as a result of rapid oxidation while an intermediate between Fe_3O_4 and γ-Fe_2O_3 forms as a product of slow oxidation.

38. Observation on Scaling of Iron. W. J. WRAZEJ. *J. Metals*, **5**, 265-266 (1953).

Micrographs showing the scale formed by oxidation of Armco iron at 700 C are presented. The ratios Fe_2O_3 to Fe_3O_4 and (Fe_2O_3 + Fe_3O_4) to FeO in the scale are greater than other investigators have found. [The composition of the scale was not determined through chemical analysis or diffraction methods.]

39. Oxidation Mechanisms of Binary Iron-Chromium Alloys at Elevated Temperatures. J. MOREAU. *Compt. Rend.*, **236**, 85-87 (1953). Through x-ray and metallographic examination the scales formed by the oxidation of chromium steels at 800 to 1250 C were analyzed. The layer adjacent to the metal was comprised of Cr embedded in FeO; the layer above this was a mixed spinel oxide containing Fe and Cr while the exterior layer consisted of α-Fe_2O_3.

40. Accelerated Oxidation of Metals at High Temperatures. A. DeS. BRASUNAS AND N. J. GRANT. *Trans. Am. Soc. Metals*, **44**, 1117-1146 (1952).

The rate and nature of the oxidation of 16 Cr—25 Ni—6Mo (or V) steels were studied in the vicinity of 2000 F. Mo and V which have low melting, volatile oxides lowered the oxidation resistance of such steels except when as much as 30 percent Ni was present. Chemical analysis of the scale showed that the concentration of Mo and V oxides was greatest at the metal-oxide interface. X-ray diffraction studies indicate that all of the oxide layers had a spinel structure.

41. The Nature of the Films Formed by Passivation of Iron with Solutions of Sodium Phosphate. M. J. PRYOR, M. COHEN AND F. BROWN. *J. Electrochem. Soc.*, **99**, 542-545 (1952).

The phosphate content of the films on iron passivated on 0.1 M phosphate solutions was determined through the use of a radioactive tracer method. The thickness of the surface film was measured by an electro-chemical technique. The phosphate content of the film decreased with rise in the pH of the passivating solution.

42. High Temperature Oxidation of Some Iron-Chromium Alloys. D. CAPLAN AND M. COHEN. *J. Metals*, **4**, 1057-1065 (1952).

The course of the oxidation of 12, 16 and 27 percent Cr steels was examined in dry and moist air at temperatures between 1600 and 2000 F. Weight-gain versus time studies, x-ray, spectrographic and metallographic techniques were employed to characterize the corrosion products. A very protective, thin, oxide film formed at low temperatures on 12 and 16 percent Cr steel. The scale on 27 percent Cr steel is mainly a Cr oxide (perhaps γ-Cr_2O_3) containing some silica.

43. The Isolation and Examination of Films from Metal Surfaces: An Improved Technique. T. J. NURSE AND F. WORMWELL. *J. Appl. Chem.*, **2**, 550-554 (1952).

The alcoholic-iodine technique for stripping oxide films from mild steel was improved. Larger pieces of film were obtained for examination by coating the surface with Formvar prior to removing the oxide film.

44. Research on the Mechanism of Oxidation of Single Crystals of Iron. J. BARDOLLE AND J. BENARD. *Rev. Met.*, **49**, 613-621 (1952).

The dependence of the rate of oxidation of iron on temperature, oxygen pressure and crystal orientation was examined with the use of microscopic and x-ray diffraction techniques. The (100) plane of FeO grows in the (110) plane of the metal.

45. Role of Crystal Orientation in the Oxidation of Iron. E. A. GULBRANSEN AND R. RUKA. *J. Electrochem. Soc.*, **99**, 360-368 (1952).

A high temperature electron diffraction reflection camera was used to determine the orientation of oxide films and scales on iron single crystals. Under slow oxidizing conditions oriented films formed on the metal crystals; the (010) direction in FeO (or Fe_3O_4 at temperatures below 570 C) grew in the (110) direction of α-Fe in every case. Randomly oriented films formed under rapid oxidizing conditions.

46. Action of Sodium Silicate as a Corrosion Inhibitor in Water Piping. L. LEHRMAN AND H. L. SCHULDENER. *Ind. Eng. Chem.*, **44**, 1765-1769 (1952).

The interaction of dilute silicate solutions with corrosion products of iron, zinc and brass was investigated. The oxide films produced on brass and iron pipes during passage of silicate solutions were analyzed by chemical analysis and x-ray diffraction. Corrosion is inhibited by the presence of silicate in water through the formation of a silica-metal hydroxide layer on top of the oxide film which is adjacent to the metal. Such a layer enmeshes Fe, Cr and Mg compounds from the water.

47. An Electron Diffraction Study of Films Formed by Sodium Nitrite Solution on Iron. M. COHEN. *J. Phys. Chem.*, **56**, 451-453 (1952).

When iron is exposed to nitrite, chromate and aerated sodium hydroxide solutions a film comprised of a spinel oxide and γ-FeOOH is formed on the metal surface.

48. A New Anodic Method for the Transfer of Oxide Films from Heat-Tinted Iron to Glass or Plastic. U. R. EVANS AND R. TOMLINSON. *J. Appl. Chem.*, **2**, 105-109 (1952).

The anodic method for film transfer is more rapid and less sensitive to the presence of oxygen than is the alcoholic-iodine technique.

49. Electron Diffraction as a Microanalytical Procedure. H. A. STAHL. *Chem. Ztg.*, **76**, 136-139, 164-169 (1952).

A review is given of the results obtained by electron diffraction examination of surfaces of alloys which have undergone various forms of corrosion. [*C.A.*, **46**, 6541i (1952).]

50. The Formation of γ-Fe_2O_3 at Low Temperature in a Strongly Hygroscopic Medium. H. E. V. STEINWEHR AND R. WEBER. *Naturwissenschaften*, **39**, 140 (1952).

The reaction between iron and an aqueous-saturated ammonia solution was studied between 0 and 50 C. X-ray diffraction indicated that a spinel oxide (probably γ-Fe_2O_3) formed on the iron surface under these conditions, whereas γ-FeOOH was formed in a similar reaction between iron and water.

51. Interaction between Iron and Ozone. R. K. BURSHTEIN AND N. A. SHUMILOVA. *Doklady Akad. Nauk. SSSR*, **83**, 251-252 (1952).

Oxidation of iron in oxygen and in oxygen-ozone mixtures at temperatures between 190 and 430 K produced slightly thicker oxide layers in the latter case. Film thickness was determined by the amount of hydrogen necessary to complete reduction of the film. [*C.A.*, **46**, 8478e (1952).]

52. The Nature of the Film Present on Iron after Brightening in Marshall's Solution. A. HICKLING, W. A. MARSHALL AND E. R. BUCKLE. *J. Electrodepositors' Tech. Soc.*, **28**, 47-68 (1952).

An electrometric method was employed for the measurement of film thickness. Some introductory diffraction measurements indicated that the film was a mixture of rhombohedral and cubic iron oxides. After removal by cathodic polarization of the film formed in Marshall's solution, an identical film could be formed by air oxidation.

53. The Mechanism of Scale Formation on Iron at High Temperature. B. W. DUNNINGTON, F. H. BECK AND M. G. FONTANA. *Corrosion*, **8**, 2-13 (1952).

The type of oxide which forms on iron depends upon the diffusion of lattice vacancies in the metal. Photomicrographs were used to determine the thickness and changes in the nature of the scale formed at various temperatures. Photomicrographic examination gave the same rate law for the formation of the surface oxide on iron at 1090 C as did a continuous weighing technique. A microhardness test aided in the identification of particular oxides in the scale.

54. Corrosion of Iron by Solutions of Iodine in Benzene. L. G. GINDIN AND M. V. PAVLOVA. *Zhir. Priklad. Khim.*, **24**, 1151-1155 (1951).

The corrosion product of iron in benzene-iodine solution was found to be Fe_2O_3 containing 3-7 percent FeI_2. Chemical analysis and x-ray techniques were employed.

55. The Oxidation of Pure Iron. J. K. STANLEY, J. VAN HOENE AND R. T. HUNTOON. *Trans. Am. Soc. Metals*, **43**, 426-445 (1951).

A Geiger counter x-ray spectrometer and a special metallographic technique were used to identify the components of scale formed by the oxidation of pure iron at 500 to 900C. At 500C the scale was essentially Fe_3O_4 but at higher temperatures α—Fe_2O_3 and FeO were also present in the scale. Weight-gain versus time-of-oxidation data show that the oxidation follows a parabolic rate law.

56. Contact Potential Variations on Freshly Condensed Metal Films at Low Pressures. L. ANTES AND N. HACKERMAN. *J. Appl. Phys.*, **22**, 1395-1398 (1951).

Contact potential measurements for Al, Cu, Au, Ni, Cr and Fe are given. It is demonstrated how this technique may be useful in studying oxidation mechanisms for metals.

57. The Etched and Corroded Surfaces of Iron Single Crystals as Revealed by Means of Electron Microscopy and Dif-

fraction. S. YAMAGUCHI. *Bull. Chem. Soc. Japan*, **24**, 237-239 (1951).

The (102) planes of Fe_3O_4 crystals in the oxide film were found to be oriented parallel to the (111) plane of the iron substrate. Chromium enhances the corrosion resistance of steel by giving rise to inert (110) planes at the metal surface.

58. A Study on Corrosion Products of Iron by Means of Electron Diffraction. R. ABE. *J. Phys. Soc. Japan*, **6**, 345-350 (1951).

In oxygen-free 0.1 percent NaCl solutions the corrosion product of iron was $Fe(OH)_2$; in air-saturated solutions the corrosion product was γ-FeOOH. All attempts to oxidize $Fe(OH)_2$ to α-FeOOH were unsuccessful.

59. On the Mechanism and Kinetics of the Scaling of Iron. M. H. DAVIES, M. T. SIMNAD AND C. E. BIRCHENALL. *J. Metals*, 3, 889-896 (1951).

The rates of oxidation of FeO to Fe_3O_4 and of Fe_3O_4 to Fe_2O_3 were studied by means of a thermobalance and were found to be diffusion-controlled processes. The transport mechanism responsible for oxide growth on iron was investigated through the use of radioactive silver markers. Above 570C the rate controlling layer changes from Fe_3O_4 to FeO.

60. Solid State Reactions in the Films of Oxide Formed on Iron. E. A. GULBRANSEN. *Rev. met.*, **48**, 336-352 (1951).

High-temperature electron diffraction techniques were employed to study solid phase reactions on iron strips during oxidation between 400 and 700C. The oxidation proceeds by diffusion of iron ions through the oxide lattice. Both the forward and reverse transformations $Fe_3O_4 + Fe \rightleftarrows 4FeO$ occur at 400C in thin films on iron.

61. Kinetics and Mechanism of Solid Phase Reactions in Oxide Films on Pure Iron. E. A. GULBRANSEN AND R. RUKA. *Ind. Eng. Chem.*, **43**, 697-703 (1951).

The mechanism of the oxidation of iron above 570C was investigated through a kinetics study employing electron diffraction techniques. Solid phase reactions between higher oxides and iron result in the formation of FeO; these reactions proceed in the presence or absence of air.

62. The Mechanism of the Inhibition of the Corrosion of Iron by Solutions of Sodium Orthophosphate. M. J. PRYOR AND M. COHEN. *J. Electrochem. Soc.*, **98**, 263-272 (1951).

Iron is passivated at room temperature by 0.1 N orthophosphate solutions at pH greater than 7.25 in air. The inhibition mechanism is believed to involve adsorption of dissolved oxygen on the Fe surface and subsequent formation of a protective film of γ-Fe_2O_3. X-ray examination and chemical analysis indicate that $Fe_3(PO_4)_2 \cdot 8H_2O$ and $FePO_4 \cdot nH_2O$ are corrosion products under non-passive conditions.

63. Mechanism of Oxidation of Pure Iron at High Temperature. J. PAIDASSI. *Bol. soc. chilena quim.*, **3**, 55-66 (1951).

A microscopic method was employed to show that the parabolic growth rates for FeO, Fe_3O_4, and Fe_2O_3 in iron scale at 850C are equivalent. The oxidation of FeO to Fe_3O_4 and Fe_3O_4 to Fe_2O_3 in the absence of an iron substrate are being examined. [*C.A.*, **46**, 11068f (1952)].

64. Studies on High Temperature Oxidation of Stainless Steels. I. ITTAKI, T. NAKAYAMA AND K. SEKIGUCHI. *J. Sci. Research Inst.* (Tokyo), **45**, 57-64 (1951).

Electron diffraction studies of the oxide layers produced on Fe-Cr-Ni and Fe-Cr alloys at 900C indicate that the presence of Ni reduces corrosion; Ni-NiO layers in the oxide film retard diffusion of metal atoms from the substrate. Molybdenum reduces the resistance of steel to oxidation; low boiling MoO_3 crystals in the film decrease the adherance of the film at high temperatures.

65. High-Temperature Oxidation of Pure Iron. J. PAIDASSI. *Ing. Quim. Univ. Concepcion*, Chile, **10**, No. 10, 5-17 (1951).

Metallographic studies indicated that the external layers of scale (Fe_3O_4 and Fe_2O_3) on iron follow a parabolic growth rate. [*C.A.*, **46**, 9486i (1952)].

66. An X-Ray Study of the Scale Formed on Iron Between 400 and 700C. O. A. TESCHE. *Trans. Am. Soc. Metals*, **42**, 641-652 (1950).

X-ray diffraction and scale thickness measurements were used to examine the composition and nature of the scale on iron. The scale which formed up to 600C was predominantly Fe_3O_4. Between oxidation temperatures 700 to 1000C the scale which formed contained FeO, Fe_3O_4, and Fe_2O_3.

67. Kinetics of Solid Phase Reactions in Oxide Films on Iron—The Reversible Transformation At or Near 570°. E. A. GULBRANSEN AND R. RUKA. *J. Metals*, 1500-1508 (1950); *Trans. Am. Inst. Metals*, **188**.

Electron diffraction studies show that both transformations $Fe_3O_4 + Fe \rightleftarrows 4FeO$ occur at temperatures as low as 400C in very thin films on pure iron. The forward transformation is controlled by diffusion of iron, while the reverse transformation is dependent upon nucleation and growth processes.

68. The Mechanism of Inhibition of the Corrosion of Iron by Sodium Hydroxide Solution. J. E. O. MAYNE, J. W. MENTER AND M. J. PRYOR. *J. Chem. Soc.*, **1950**, 3229-3236.

Polarization studies, chemical analysis and electron diffraction studies were employed to show that dissolved oxygen reacts with iron in sodium hydroxide solution to form a film of protective γ-Fe_2O_3 on the metal surface.

69. Formation of Oxides on Some Stainless Steels at High Temperatures. H. M. MCCULLOUGH, M. G. FONTANA AND F. H. BECK. *Am. Soc. Metals*, Preprint No. 4, 17 pp. (1950).

The course of oxide growth on Types 304, 430 and 410 stainless steels was examined by use of a continuous weighing process. Chemical analysis and electron diffraction techniques showed that the oxide consisted of $FeCr_2O_4$ and α-Fe_2O_3. Oxidation rates from 1500 to 1800F were obtained.

70. Optical Studies of the Oxidation of Iron at Temperatures in the Range 20-265C. A. B. WINTERBOTTOM. *J. Iron and Steel Inst.*, **165**, 9-22 (1950).

A polarimetric method was employed to follow the oxide growth on iron and on some Fe-Cr-Ni iron alloys. Through the use of this technique it was shown that the films up to thickness of about 250 Å consist of Fe_3O_4 or γ-Fe_2O_3. Thicker films have an exterior layer of α-Fe_2O_3.

71. The Reductive Dissolution of Ferric Oxide in Acid. Part I. The Reductive Dissolution of Oxide Films Present on Iron. M. J. PRYOR AND U. R. EVANS. *J. Chem. Soc.*, **1950**, 1259-1266.

The oxide film obtained by heating iron at 210C for 30 hours was identified by electron diffraction as α-Fe_2O_3. The destruction of the iron oxide film by acid was attributed to reductive dissolution as Fe(II) ions. The rate of destruction increased with solution temperature and decreased with pH.

72. Experimental Investigations on the Reaction Between Steam and Iron. K. WICKERT AND H. PILZ. *Werkstoffe u Korrosion*, **1**, 56-64 (1950).

Low carbon steel boiler plate begins to react with steam at 410C; stainless steel begins to react at 780C. Iron reacts with wet oxygenated steam to form $Fe(OH)_3$ and with dry oxygenated steam to form a protective coating of oxides.

73. Corrosion of Wet Steel by Hydrogen Sulfide-Air Mixtures. D. C. BOND AND G. A. MARSH. *Corrosion*, **6**, 22-28 (1950).

The corrosion rate of wet mild steel in H_2S-air mixtures from 70 to 120F was determined. The ratio of iron present as sulfide in the corrosion product to that present as hydrated oxide was measured as a function of H_2S concentration. Hydrated iron oxide converted to iron sulfide in the presence of H_2S more rapidly than the sulfide converted to the oxide in the presence of oxygen.

74. The Dark Green Hydroxyl Compound of Iron. V. N. FEITKNECHT AND G. KELLER. *Z. anorg. Chem.*, **262**, 61-68 (1950).

X-ray and chemical analysis lead to the formulation $4Fe(OH)_2 \cdot FeOCl \cdot H_2O$ for the green rust which appears on iron which has been exposed to salt water.

75. Adsorption Balance for Investigation of Metal Corrosion at High Temperatures. I. A. MAKOLKIN. *Zavodskaya Lab.*, **15**, 1209-1212 (1949).

A balance for continuous measurement of weight changes taking place during high temperature corrosion is described. [*C.A.*, **44**, 996h (1950).]

76. Mechanism of Iron-Rust Formation. R. ABE, E. YOSHIOKA AND R. UEDA. *Science* (Japan), **19**, 472 (1949).

An electron diffraction study of the rust on iron indicated that green rust, which has the formula $2FeO \cdot Fe_2O_3 \cdot H_2O$, decomposes into FeO and Fe_3O_4 when heated in vacuo. [*C.A.*, **45**, 5496d (1951).]

77. Electron Diffraction Studies on the Nature of the Corrosion Resistance of Stainless Steel. On the Ferrous Nickel Chromate Formed on the Surface of Stainless Steel. S. YAMAGUCHI, T. NAKAYAMA AND T. KATSURAI. *Trans Electrochem. Soc.*, **95**, 21-24 (1949). (Discussion, pp. 347-349).

The structure of the oxides formed on 19-9 and 18-4 chromium-nickel steels during treatment with water vapor in an autoclave at 180 to 190 C was examined.

Electron diffraction studies indicate the corrosion film on both types of steel to be a solid solution of $NiCrO_4$ and $FeCrO_4$. The authors point out that such a film provides corrosion resistance through 1) chemical stability and 2) ability to bind tightly with the substrate.

78. The Mechanism of Direct Dissolution of Ferric Oxide. M. J. PRYOR AND U. R. EVANS. *J. Chem. Soc.*, **1949,** 3330.

When iron oxides prepared by precipitation from ferric ammonium sulfate solution with aqueous ammonia were ignited at temperatures below 300 C an amorphous product was obtained. Ignition of the precipitate at temperatures above 385 C produced α-Fe_2O_3 crystals as determined by x-ray examination. Dissolution of α-Fe_2O_3 was rapid in fluoride and concentrated chloride solutions, but was much slower in the dilute chloride, sulfate and perchlorate solutions.

79. Information on the Corrosion of Heat-Resistant Steels by Oils Containing Vanadium. V. P. SCHLAPFER, P. AMGWERD AND H. PREIS. *Schweiz. Arch. angew. Wiss. u. Tech.*, **15,** 291-299 (1949).

Vanadium-containing oils destroy the protective oxide film on high alloy steels. X-ray diffraction data show that $FeVO_4$ and $CrVO_4$ are present in the scale formed on steel at 900 C in the presence of these oils. Attack is more rapid in the presence of air or alkali. Molybdenum-containing steels are particularly susceptible to this form of corrosion.

80. The Crystallochemical Mechanism of Formation of Oxide Films on Iron at Room Temperature. P. D. DANKOV AND N. A. SHISHAKOV. *Zhur. Fiz. Khim.*, **23,** 1031-1035 (1949).

Iron films were prepared by condensation of the metal vapor at pressures in the neighborhood of 10^{-4} mm. of Hg. The electron diffraction pattern of such films contains lines of FeO, Fe_3O_4 and γ-Fe_2O_3. The conclusion reached from this study is that during transformation of the wüstite layer to a spinel layer Fe ions diffuse from the metal into the tetrahedral sites of the spinel lattice. The octahedral sites are occupied by Fe ions which have not changed their original position from that in the wüstite lattice. *C.A.*, **44,** 894a (1950).

81. Identification of Corrosion Products Using Measurements of Film Thickness and Mass. C. EILERTS. *Ind. Eng. Chem.*, **41,** 1716-1717 (1949).

An equation is given for calculating the density of corrosion products on steel from the thickness and weight of the oxide film. Densities of corrosion products identified by x-ray diffraction correlated well with the calculated values.

82. Kinetics of the Corrosion Process in Condensate Gas Wells. N. HACKERMAN AND H. R. SCHMIDT. *Ind. Eng. Chem.*, **41,** 1712-1716 (1949).

The corrosive agents in natural gas-condensate wells are fatty acids and moist carbon dioxide. Rate curves for corrosion of 1020 steel in this environment are given. Diffraction techniques showed that the corrosion products were ferrous carbonate and a spinel oxide. In some wells very little corrosion was observed; this was attributed to the presence of a natural inhibitor which was probably organic in nature.

83. Kinetic and Structural Factors Involved in Oxidation of Metals. E. A. GULBRANSEN. *Ind. Eng. Chem.*, **41,** 1385-1391 (1949).

Oxidation mechanisms for Fe, Al, Mo, W and Mg were investigated through the use of electron diffraction and microscopy techniques.

84. The Mechanism of Inhibition of Corrosion of Iron by Chromic Acid and Potassium Chromate. J. E. O. MAYNE AND M. J. PRYOR. *J. Chem. Soc.*, **1949,** 1831-1835.

Chemical analysis and electron diffraction techniques indicate that the oxide film formed on iron during exposure to chromate solutions is largely γ-Fe_2O_3.

85. New Methods for the Routine Gravimetric Analysis of Boiler Scales and Deposits Containing Phosphate. J. C. EDWARDS AND G. P. ALCOCK. *J. Soc. Chem. Ind.*, **68,** 168-171 (1949).

A method employing the use of 8-hydroxyquinoline as a percipitant for iron, aluminum and magnesium to avoid interference with phosphate is desired.

86. The Practical Problems of Corrosion. Part XII. The Influence of Corrosion on the Thermal Deposition of Calcium Carbonate. J. N. WANKLYN AND U. R. EVANS. *J. Soc. Chem. Ind.*, **68,** 171 (1949).

A mixture of calcite and aragonite are products of the cathodic treatment of steel in cold calcium carbonate solution. X-ray diffraction techniques were employed.

87. Sodium Nitrite as an Inhibitor Against the Attack of Sea Water on Steel. Part I. The influence of Sodium Nitrite on the Area and Intensity of Attack. D. WYLLIE AND G. C. N. CHEESMAN. *J. Soc. Chem. Ind.*, **68,** 165 (1949).

The action of sea water on steel results in precipitation of a red hydrous oxide. Nitrite inhibitor produces a brown-colored film on the steel. Corrosion currents were measured.

88. An Investigation of the Decomposition Process of Iron (II) Oxide. G. CHAUDRON AND J. BENARD. *Bull. soc. chim. France,* Ser. 5, **16,** D. 117-119 (1949).

Thermomagnetic and micrographic techniques were used to examine the decomposition on wüstite into magnetite and iron at temperatures between 600 and 1000 C. The rate of decoposition was dependent on the temperature of preparation, on the composition (whether iron or oxygen-rich) of the wüstite phase and on the presence of nuclei of Fe or Fe_3O_4.

89. An Investigation of the Variable Composition of Iron (II) Oxide. J. BENARD. *Bull. soc. chim. France,* Ser. 5, **16,** D. 109-116 (1949).

Chemical analyses, magnetic studies and x-ray methods were employed to determine the nature of the oxide formed by oxidation of iron at temperatures between 570 and 1100 C. An oxide phase with stoichiometric composition FeO exists in solid solution with Fe at temperatures above 750 C.

90. The Oxidation of Metals and Reactions in the Solid State. J. BENARD. *Bull. soc. chim. France,* Ser. 5, **16,** D. 89-95 (1949).

The structure of the scale formed by oxidation of iron in the A_3 transformation region was examined microscopically. The dependence of the oxidation on the orientation of the metal crystals was investigated. A mechanism by which metal atoms diffuse into the oxide scale was developed.

91. Melting Points of Iron Oxides on Silica; Phase Equilibria in the System Fe-Si-O as a function of Gas Composition and Temperature. L. S. DARKEN. *J. Am. Chem. Soc.*, **70,** 2046-2053 (1948).

The phase diagram for the Fe-Si-O system above 700 C was constructed. Data from this study were employed in interpreting the migration of silica to the metal surface during oxidation of steel. The fact that the activity of silica was found to be a minimum at the scale-metal interface accounts for the tendency for silica to migrate to and remain in this region.

92. The Breakdown of Oxide Films in Acid Vapours. V. W. FEITKNECHT. Pittsburgh International Conference on Surface Reactions, pp. 212-221 (1948).

The corrosion products formed by exposure of Zn, Cd, Ni, Fe and Cu to HCl at various partial pressures were characterized through the use of microscopic examination and diffraction techniques. An electrochemical mechanism was preposed to account for the breakdown of oxide films and atmospheric corrosion by acid vapors.

93. Mechanism of the Rapid Oxidation of High-Temperature, High-Strength Alloys Containing Molybdenum. W. C. LESLIE AND M. G. FONTANA. Pittsburgh International Conference on Surface Reactions, pp. 173-186 (1948).

The structure and composition of the oxide formed on 16% Cr 25% Ni 6% Mo steel were determined. Chemical analysis, x-ray and electron diffraction and metallographic examination were employed in this work. The failure of this steel under high-temperature oxidizing conditions was attributed to thermal decomposition of MoO_3.

94. Investigations of Gas-Metal Reactions by Reflection Electron Diffraction. J. W. HICKMAN. Pittsburgh International Conference on Surface Reactions, pp. 142-156 (1948).

Electron diffraction patterns of the metal surfaces made during the high temperature oxidation of Fe, Co, Mo, W, Cu, Cr and Ni are given. The size and orientation of the oxide crystallites was examined.

95. Some Recent Contributions of a British Corrosion Research Group. W. H. J. VERNON. Pittsburgh International Conference on Surface Reactions, pp. 135-141 (1948).

Several techniques for studying aqueous and atmospheric corrosion are discussed. A film stripping apparatus, an electron micrograph study, an electron diffraction investigation and the results of a chemical analysis of the film from stainless steel are described. The air-formed oxide film on 18/8 stainless steel appears to be enriched with chromium but the extent of enrichment is influenced by the degree and nature of polishing. The air-formed film on mild steel contains about equal amounts of α-Fe_2O_3 and spinel oxide.

96. Application of the Electron Microscope in Corrosion Studies. E. M. MAHLA AND N. A. NIELSEN. Pittsburgh

International Conference on Surface Reactions, pp. 60-66 (1948).

In conjunction with other techniques electron microscopy is useful for studying corrosion phenomena. Intergranular corrosion and the effect of grain orientation on corrosion of stainless steels was investigated.

97. Electropotentials in Growing Halide and Oxide Layers on Metals. A. Dravnieks and H. J. McDonald. *Trans. Electrochem. Soc.*, **93**, 177-190 (1948)

An electrode probe technique was employed to measure the ionic transference numbers in growing oxide scales on Fe, Ni, stainless steel, Cu, Zn, brass, Al, W and Mo.

98. A Study of Films Isolated From Passive Stainless Steels. E. M. Mahla and N. A. Nielsen. *Trans. Electrochem. Soc.*, **93**, 1-16 (1948).

Thin, transparent films were formed upon exposure of chromium, stainless steels and nickel-chromium alloys to air, HNO_3, and HNO_3-$K_2Cr_2O_7$ solutions. A bromine-methanol solution was used in stripping the films. Spectrographic and quantitative chemical analyses of the films were made. Microscopic and diffraction techniques aided in characterizing the corrosion products.

99. Solution and Passivation of Iron in Alkaline Solutions. B. Kubanov and D. Leikis. *Doklady Akad. Nauk., USSR*, **58**, 1685-1688 (1947); *Chem. Zentr.*, **1949**, 28.

The influence of various factors on the overvoltage and the yield of the process $Fe \rightarrow Fe(OH)_2$ taking place on a pure iron electrode was examined. Anodic dissolution and passivation of iron in alkaline solution involve transition of iron into $HFeO^-_2$ and subsequent precipitation of $Fe(OH)_2$. [*C.A.*, **46**, 6515 (1952).]

100. Effect of Carbide Structure on the Corrosion Resistance of Steel. R. W. Manuel. *Corrosion*, **3**, 415-431 (1947).

The corrosion resistance of low alloy steels was examined with attention being given to the effect of carbide structure which is dependent on heat treatment and alloying elements. Metallographic and x-ray diffraction techniques were useful in this study.

101. An Electron Diffraction Study of Oxide Films Formed on High Temperature Oxidation Resistant Alloys. J. W. Hickman and E. A. Gulbransen. *Trans. Electrochem. Soc.*, **91**, 605-622 (1947).

The oxidation products of a variety of high alloy steels were examined by electron diffraction at 300 to 900 C. The oxide films consisted largely of an iron-chromium spinel and of Cr_2O_3, but nickel was never detected by spectrographic analysis of the scale.

102. High Temperature Oxidation. H. M. McCullough. Ohio State Univ. Studies. *Eng. Exp. Sta. News*, **19**, 38-41 (1947).

The corrosion rates at temperatures between 850 and 2100 F of Types 304 and 410 stainless steel were measured by weight gain and weight loss techniques. The scales were chemically analyzed and examined microscopically. A compact protective chrome-iron spinel oxide formed under conditions of low oxygen concentration while a porous non-protective iron oxide formed a higher oxygen concentration.

103. Passivation of Stainless Steel. F. H. Beck. Ohio State Univ. Studies. *Eng. Exp. Sta. News*, **19**, 32-38 (1947).

The mechanism responsible for passivation of 18/8 stainless steel by sulfuric acid solutions was investigated. Studies were made on the effect of vacuum exposure upon the corrosion resistance of passivated specimens. The surface films were examined by electron diffraction. The results indicate that passivation is effected by physical adsorption of gas on either the metal surface or on a hydrous oxide film.

104. Oxide Films Formed on Alloys at Moderate Temperatures. Electron Diffraction and Electron Microscope Study. E. A. Gulbransen, R. T. Phelps and J. W. Hickman. *Ind. Eng. Chem.*, Anal. Ed., **18**, 640-652 (1946).

The composition of the oxide films on alloys of Fe, Cr, Ni and Co was reported on the basis of reflection and transmission electron diffraction data. The size and orientation of the film crystallites were determined by electron microscopy.

105. An Electron Diffraction Study of the Films Formed on Alloys of Iron, Cobalt, Nickel, and Chromium at High Temperatures. J. W. Hickman and E. A. Gulbransen. *Trans. Am. Inst. Mining Met. Engrs.*, **171**, 344-388 (1947); *Metals Tech.*, **13**, Tech. Pub. No. 2069, October, 1946.

Examination of oxide films formed by oxidation of alloys at temperatures in the range 100 to 700 C showed that the composition of the films may not be correlated with the composition of the alloys. Fe and Cr ions diffused to the metal surfaces more readily than Ni which was present only in oxide films on 80 Ni/20 Cr alloys.

106. An Electron Diffraction Study of the Oxide Films Formed on Iron, Cobalt, Nickel, Chromium and Copper at High Temperatures. E. A. Gulbransen and J. W. Hickman. *Trans. Am. Inst. Mining Met. Engrs.*, **171**, 306-343 (1947); *Metals Tech.*, **13**, Tech. Pub. No. 2068, October, 1946.

Electron diffraction data are given for the oxide films formed on various metals under different conditions of oxidation.

107. Optical Methods of Studying Films on Reflecting Bases Depending on Polarization and Interference Phenomena. A. B. Winterbottom. *Trans. Faraday Soc.*, **42**, 487-495 (1946).

The theory essential to the determination of oxide film thickness on metals by reflectivity measurements is developed. Data from measurements made on the thickness of films on Al, Cu and Fe compare favorably with gravimetric and electrometric determinations.

108. The Products of Corrosion—Iron Oxides, Hydrated Oxides and Hydroxides. R. C. Corey. *Combustion*, **18**, 45-51 (1946).

A brief resume of the chemical and physical properties of the iron oxides and hydroxides is given.

109. Electron Diffraction and Electron Microscope Study of Oxide Films Formed on Metals and Alloys at Moderate Temperatures. Stripped Oxide Films of Metals. R. T. Phelps, E. A. Gulbransen and J. W. Hickman. *Ind. Eng. Chem.*, Anal. Ed., **18**, 391-400 (1946).

Electron micrographs and electron diffraction patterns of the oxide films on Cr, Co, Mo, Ni, Al, Nb and W are given. The size of the crystals in the metal oxide films ranges from 100 to 2500 Å.

110. Oxidation of Iron at High Temperatures Determined Metallographically. J. Benard and O. Coquelle. *Rev. met.*, **43**, 113-124 (1946).

The scale formed on iron above the A_3 transformation at 910 C is different in structure from that formed at lower temperatures. A linear rate law holds for the formation of Fe_2O_3 and Fe_3O_4 while a parabolic law holds for the formation of FeO. *C.A.*, **41**, 3418c (1947).

111. Passivation of Stainless Steel. E. M. Mahla and N. A. Nielsen. *Trans. Electrochem. Soc.*, **89**, 167-189 (1946).

Chromium-iron alloys and 18/8 stainless steel were exposed to a variety of passivating solutions at 60 C. Solutions of nitric, sulfuric, acetic, lactic and formic acids along with dichromate were employed as passivators. Reflection electron diffraction studies showed that Cr_2O_3 is the major constituent of the surface oxide produced by chemical and air oxidation of 18/8. Mixtures of iron oxides form on the surfaces of chromium-iron alloys as a result of oxidation.

112. An Electron Diffraction Camera for the Study of High Temperature Surface Reactions. E. A. Gulbransen. *J. Appl. Phys.*, **16**, 718-724 (1945).

Apparatus for studying physical and chemical reactions on metal surfaces at elevated temperatures is described.

113*. The System Iron-Oxidation. I. The Wüstite Field and Related Equilibria. L. S. Darken and R. W. Gurry. *J. Am. Chem. Soc.*, **67**, 1398-1412 (1945).

A strip of iron or iron oxide was suspended in a known, small temperature gradient in a CO_2-CO environment of definite composition. The temperature corresponding to the line separating the two phases at equilibrium on the specimen was measured. The ratio Fe(II)/Fe(III) was determined by titration with permanganate, reduction with a Jones reductor and subsequent titration with permanganate. As a result of this study the activity of any iron-oxygen complex can be computed. The values obtained for the heat of formation of magnetite at 1250 and 25 C agree well with those of other investigators.

114. A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere. H. R. Copson. *Am. Soc. Testing Materials, Proc.*, **45**, 554-580 (1945).

Techniques employed in this study include weight-loss-versus-time data and chemical analysis of the corrosion products. A corrosion mechanism was postulated in which the rate and extent of corrosion is dependent on the quality and quantity of water reaching the steel surface. Insoluble corrosion products plug pores in the oxide coating formed during corrosion of metals. Sulfates produced by sulfate corrosion of alloy steels are relatively insoluble; accordingly, the extent of corrosion is less for alloy steels than for mild steel.

115. Comparative Corrosion Resistance to Seawater of Low-Alloy, High Strength Steels. J. F. J. Thomas and A. C. Halferdahl. *Can. Chem. Proc. Ind.*, **29**, 43-48 (1945).

Several types of descaling solutions

were employed for the removal of corrosion products from low alloy steel specimens which had been submitted to salt water corrosion. The extent of corrosion was determined and the rust was analyzed chemically. Small amounts of Cu, Ni, Cr and/or Mo improve the corrosion resistance to intermittent or partial immersion in sea water but reduce the corrosion resistance under conditions of total immersion in aerated sea water.

116. Solubility of Ferrous Oxide in Pure Solid Iron. A. PORTEVIN AND L. GUILLET. *Engrs. Digest*, **1**, 494-495 (1944).

Micrographic examination shows that above 800 C the oxide present on iron dissolves in iron. Above 1000 C iron oxide disappears from the metal surface entirely.

117. A Study of the Surface Film on Chromium-Nickel (18/8) Stainless Steel. W. H. J. VERNON, F. WORMWELL AND T. J. NURSE. *J. Iron Steel Inst.*, **150**, 81-92 (1944).

An iodine-methanol solution was employed to strip oxide films from 18/8 steel. The stripped films were subjected to chemical analysis. The composition of the film was dependent on the degree and method of polishing and on the temperature of oxidation. The film was enriched with chromium but not with nickel.

118. The Corrosion of Alloy Steels by High-Temperature Steam. G. A. HAWKINS, J. T. AGNES AND H. L. SOLBERG. *Trans. Am. Soc. Mech. Engrs.*, **66**, 291-295 (1944).

Unstressed specimens of low carbon, chromium and chromium-nickel steels were exposed to steam at temperatures between 1000 and 1800 F. The scale removed from the corroded specimens was analyzed chemically.

119. High-Temperature-Steam Corrosion Studies at Detroit. I. A. ROHRIG, R. M. VANDUZER AND C. H. FELLOWS. *Trans. Am. Soc. Mech. Engrs.*, **66**, 277-290 (1944).

The effect of steam at 380 psi and 925 to 1100 F on 46 different metals and alloys was investigated. Weight-loss, hardness, metallographic and corrosion rate data were obtained.

120. The Crystal Structures of Fe, FeO, and Fe_3O_4 and their Interrelations. H. J. GOLDSCHMIDT. *J. Iron Steel Inst.*, **146**, 157-180 (1942).

An investigation was made as to why α-Fe_2O_3 is never found among the corrosion products when iron is oxidized in a limited supply of oxygen. X-ray diffraction measurements were used to show the structural relationships between γ-Fe and FeO and between α-Fe and Fe_3O_4 Hematite, being of rhombohedral symmetry, is not structurally related to the cubic structures of Fe and Fe_3O_4.

121. A Study on the Corrosion of Iron by Electron Diffraction. S. MIYAKE. *Sci. Papers Inst. Phys. Chem. Research* (Tokyo), **36**, 363-370 (1939).

The corrosion of Armco iron in water and 1 percent NaCl solution was investigated at room temperature. An outermost layer of rust was identified as γ-FeOOH and an innermost layer, as γ-Fe_2O_3. Electron diffraction examination of intermediates in the dehydration of γ-FeOOH show that a corrosion product of composition intermediate in composition to γ-FeOOH and γ-Fe_2O_3 can exist.

122. The pH, Dissolved Iron Concentration, and Solid Product Resulting from the Reaction between Iron and Pure Water at Room Temperature. R. C. COREY AND T. J. FINNEGAN. *Proc. Am. Soc. Testing Materials*, Preprint No. 101, 12 pp. (1939).

At room temperature water dissolves up to 0.2 ppm of iron. The equilibrium pH is 8.3. A solid product identified by x-ray diffraction as Fe_3O_4 is formed in the reaction of iron with water.

123. The Primary Oxide Film on Iron. H. R. NELSON. *J. Chem. Phys.*, **5**, 252-259 (1937).

Electron diffraction studies were employed to examine the structure of air-formed films on iron. Fe_3O_4 or γ-Fe_2O_3 were observed to comprise the film. The oxide has a definite orientation relationship with the metal substrate.

124. Study of Oxide Films on Metal Surface With Cathode-Ray Diffraction. II. Iron, Chromium, Nickel and Their Alloys. S. MIYAKE. *Sci. Papers Inst. Phys. Chem. Research* (Tokyo), **31**, 161-173 (1937).

The oxide film which forms on iron at temperatures below 200 C is Fe_3O_4. At higher temperatures a layer of α-Fe_2O_3 lies above the Fe_3O_4 which is at the metal interface. The film on Fe-Al and Fe-Ni alloys is α-Fe_2O_3. A mixture of $FeCr_2O_4$, Cr_2O_3 and a solid solution of $Cr_2O_3Fe_2O_3$ comprises the film on Cr-Fe alloys. [*C.A.*, **31**, 4244[6] (1937.)]

125. Examination of Passive Iron by Electron Diffraction. I. IITAKA, S. MIYAKE AND T. IIMORI. *Nature*, **139**, 156 (1937).

Films were detached from iron following passivation in chromate solution. Electron diffraction transmission patterns indicate that either γ-Fe_2O_3 or Fe_3O_4 comprise the film.

126. The Thickness of Oxide Films on Iron. H. A. MILEY. *Iron Steel Inst. Carnegie Scholarship Mem.*, **25**, 197-212 (1936).

Film thickness was determined by measurement of the amount of electricity required to reduce the oxide. Values obtained in this manner were compared with optical and gravimetric determinations. The explanation for failure to observe interference colors at temperatures below 200 C is that at these temperatures Fe_3O_4 or γ-Fe_2O_3 (cubic structures) exist on the iron (cubic structure) surface. At higher temperatures α-Fe_2O_3 (rhombohedral structure) which is optically discontinuous with iron appears in the film and produces the interference colors.

127. A Laboratory Study of the Atmospheric Corrosion of Metals. W. H. J. VERNON. *Trans. Faraday Soc.*, **31**, 1668-1700 (1935).

The oxidation of iron proceeds by a different mechanism above 200 C than at lower temperatures. Only above 200 C may interference colors be produced with precision. Electron diffraction studies show that the oxide film on iron which has been oxidized below 200 C is γ-Fe_2O_3 or Fe_3O_4 while above 200 C α-Fe_2O_3 is also formed.

128. The Passivity of Metals, Part VII. The Specific Function of Chromates. T. P. HOAR AND U. R. EVANS. *J. Chem. Soc.*, 1932, 2476.

Iron (III) but never iron (II) was found to be a product of the reaction of $FeSO_4$ and K_2CrO_4 in alkaline solution. Following the corrosion of mild steel in chloride-chromate solutions Cr (III) along with Fe(III) was detected in both a loosely held oxide layer and a tightly bound oxide film on the metal surface.

130. The Passivity of Metals. Part I. The Isolation of the Protective Film. U. R. EVANS. *J. Chem. Soc.*, **1927**, 1020.

Oxide films were removed from iron by dissolution of the metal with either iodine or anodic treatment. Certain general observations concerning the interference colors, composition and protective qualities of iron oxide films are discussed.

PART 5—AUTHOR INDEX

Abstract numbers follow authors' names.

Abe, R. 58, 76
Agar, J. N. 7
Agnes, J. T. 118
Alcock, G. P. 85
Amgwerd, P. 79
Andrew, K. F. 8
Antes, L. 56
Austin, A. E. 2

Bardolle, J. 3, 45
Beck, F. H. 53, 70, 103
Benard, J. 44, 88, 89, 90, 110
Berk, A. A. 13
Berry, C. W. 23
Binder, W. O. 25
Birchenall, C. E. 28, 59
Bond, D. C. 73
Brand, B. G. 2
Brasunas, A. deS. 40
Brown, F. 41
Buckle, E. R. 52
Burshtein, R. K. 51

Calnan, E. A. 35
Caplan, D. 42
Carroll, K. G. 29
Caule, E. J. 34
Chaudron, G. 26, 88
Cheesman, G. C. N. 87
Chessick, J. J. 15
Christensen, N. 4
Clews, C. J. B. 35
Cohen, M. 31, 34, 41, 42, 47, 62
Collongues, R. 24
Copson, H. R. 114
Coquello, O. 110
Corey, R. C. 108, 122

Dankov, P. D. 80
Darken, L. S. 91, 113
Davies, D. E. 7
Davies, M. H. 59
Douglas, D. L. 11
Dravnieks, A. 97
Dulis, E. J. 29
Dunnington, B. W. 53

Edwards, J. C. 85
Eilerts, C. 81
Evans, U. R. 7, 48, 71, 86, 128, 129

Feitknecht, V. W. 74, 92
Fellows, C. H. 119
Feng, I-Ming 6
Finnegan, T. J. 122
Fisher, R. M. 39
Fontana, M. G. 53, 69, 93
Fowler, R. 11

Gindin, L. G. 54
Glenn, E. E. 26
Goldschmidt, H. J. 120
Grabowski, H. A. 1
Grant, N. J. 20, 40
Greener, C. H. 36
Guillet, L. 116
Gulbransen, E. A. ..8, 19, 45, 60, 61, 67, 83, 101, 104, 105, 106, 109, 112
Gurry, R. W. 113

Hackerman, N. 26, 56, 82
Halferdahl, A. C. 115
Hall, A. M. 5
Hawkins, G. A. 118
Hickling, A. 52
Hickman, J. W. 94, 101, 104, 105, 106, 109
Himmel, L. 28
Hoar, T. P. 128
Hoene, J. van 55
Huntoon, R. T. 55

Iimori, T. 125
Iitaki, I. 64, 125

Katsurai, T. 77
Keith, R. E. 10
Keller, G. 74
Khlapova, A. N. 33
Kolthoff, I. M. 30
Kubanov, B. 99

Lehrman, L. 46
Leikis, D. 99
Leslie, W. C. 93
Leussing, D. L. 30

Mahla, E. M. 96, 98, 111
Makolkin, I. A. 75

Manuel, R. W. 100
Marsh, G. A. 73
Marshall, W. A. 52
Mayne, J. E. O. 16, 17, 37, 68, 84
McCullough, H. M. 69, 102
McDonald, H. J. 97
McMillan, W. R. 8
Mehl, R. F. 28
Menter, J. W. 16, 17, 68
Miley, H. A. 126
Miyake, S. 121, 124, 125
Monkman, F. C. 20
Moreau, J. 3, 39
Mott, B. W. 27

Nakayama, T. 64, 77
Neat, F. U. 13
Nelson, H. R. 123
Nielsen, N. A. 96, 98, 111
Nurse, T. J. 35, 43, 117

Paidassi, J. 63, 65
Pavlova, M. V. 54
Phelps, R. T. 104, 109
Pilz, H. 72
Portevin, A. 116
Pray, H. A. 22, 23
Preis, H. 79
Pryor, N. J. 14, 21, 31, 41, 62, 68, 71, 78, 84

Rhodin, T. N. 9, 18
Rohrig, I. A. 119
Ruka, R. 45, 61, 68

Schlapfer, V. P. 79
Schmidt, H. R. 82
Schuldener, H. L. 46
Sekiguchi, K. 64
Shishakov, N. A. 80
Shumilova, N. A. 51
Siebert, C. A. 10
Sifferlen, R. 24
Simnaud, M. T. 59
Sinha, B. C. 32
Sinnott, M. J. 10
Solberg, H. L. 118
Stahl, H. A. 49
Stanley, J. K. 55
Steinwehr, H. E. V. 50
Stephan, E. F. 22

Tesche, O. A. 66
Thomas, J. F. J. 115
Tomlinson, R. 48

Ueda, R. 76
Uhlig, H. H. 6

VanDuzer, R. M. 119
Vernon, W. H. J. 35, 95, 117, 127

Wanklyn, J. N. 86
Weber, R. 50
Weisert, E. D. 25
Wickert, K. 72
Winterbottom, A. B. 70, 107
Wormwell, F. 43, 117
Wrazej, W. J. 38
Wyllie, D. 87

Yamaguchi, S. 57, 77
Yearian, J. J. 12
Yoshioka, E. 76

Zernike, J. 32
Zettlemoyer, A. C. 15
Zyzes, F. C. 11

An Impressed Current Cathodic Protection System Applied to a Submarine*

By E. E. NELSON

Introduction

THE NAVAL RESEARCH Laboratory, as part of the program initiated by the Bureau of Ships of applying cathodic protection to reduce the corrosion damage to underwater hulls of ships, was authorized to design and supervise the installation and operation of an impressed current system for a fleet-type submarine.

The problem of devising a system that would conform to good design practice for submarines was resolved by consulting with the various interested groups at the Portsmouth Naval Shipyard. Such a system was installed on the submarine at the Philadelphia Naval Shipyard in February and March of 1953. The ship then engaged in active duty until March 1954 at which time it was dry-docked at the Charleston Naval Shipyard.

As a result of dry-dock inspection and a review of the year's operation, some important modifications of the design were judged to be desirable. These modifications were accomplished at the Charleston Naval Shipyard in March and April of 1954. This report contains a description of the cathodic protection system installed at that time, typical operating data and some conclusions drawn from a dry-dock inspection in February, 1955 after approximately ten months of ship operation.

Details of Cathodic Protection System

The principal parts of the installation are shown by the wiring diagram (Figure 1). Cabinet I contains a potentiometer and circuit for obtaining hull potential readings. Cabinet II contains an electrically driven motor for automatically adjusting the total current as described below, while Cabinet III consists of a transformer and full wave rectifier.

The anodes consist of copper rod ⅛ inch in diameter and 48 inches long clad with 0.005 inch of platinum (20 percent palladium) alloy. There were a total of 11 anodes; two were located above the normal water line and nine below. The locations of the anodes as well as the reference electrodes are shown in Figure 2.

A sketch of the steel anode holder is shown in Figure 3. The silver-soldered junction between the anode and the rubber covered copper cable was covered with a thermosetting neoprene seal to prevent any contact of the copper with sea water.

The selenium rectifier was full wave with a rated output of 132 amperes. The voltage input was controlled by a variable auto transformer which could be manually operated or could be regulated automatically by an electric motor driven by an electronic amplifier. The input signal to the amplifier was the voltage difference between the ship's potential and a voltage taken from a dry cell, called "bucking voltage" in Figure 1. The amplifier either increased or decreased the cathodic protection current so that this voltage difference would be very nearly zero. Thus the ship's potential is adjusted to equal the voltage taken from the dry cell.

The automatic control was not evaluated during the test program as it was found that the current requirements were about equal to the maximum current obtained from the rectifier under the operating conditions. Thirteen silver-silver chloride reference electrodes were spaced about the hull and superstructure. A selector switch permitted reading of the potential difference between each reference electrode and the hull.

The cathode areas surrounding the anodes were covered with special shielding material to avoid large current to these areas. Surrounding the seven anodes on the outer hull, a 12 foot by 8 foot area was covered with one layer of 1/16 inch thick neoprene cemented to the hull with a cold process neoprene adhesive. Flat steel strips overlapping the edges were welded around the periphery of the shields.

The two anodes behind the port and starboard

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Abstract

A cathodic protection system using platinum-clad copper anodes on neoprene shields was installed on a fleet-type submarine. Current was supplied from a rectifier to 11 anodes distributed over the hull, the potential being monitored by 13 silver-silver chloride electrodes at selected locations. The system was operated for a ten-month period of active duty after which inspection on a marine railway showed the hull to be in excellent condition with the vinyl paint functioning well. Three of the anodes were damaged but all the cable seals, insulators and anode shields were found intact. The use of platinum-clad anodes of the type employed seems economically feasible since the cost of these anodes constitutes a small part of the cost of installation. Laboratory tests indicate the desirability of replacing the copper anode core by a silver core as an insurance against anode failure in the event of a perforation of the platinum cladding. 5.2.3

★ Submitted for publication June 11, 1956.

torpedo shutters were surrounded by a 12 foot by 8 foot shield of neoprene paint built up to 0.050 inch thickness. The two anodes on top of the pressure hull did not have any special shielding material but were surrounded by the standard vinyl paint system for hulls, which was used for the entire exterior of the ship.

Operation of the Modified System

After a brief period of operations at sea the submarine was berthed at Key West early in June of 1954, a separate berth being provided so that the ship could be more easily electrically isolated from other structures. After isolation was obtained, the potential measured at electrode No. 9 rose from 0.60 to 0.85 volt. These potentials, as well as all others reported, are negative with respect to the silver-silver chloride reference electrode. At this time, with a 57 ampere current flowing, potential readings were made about the ship by means of an auxiliary electrode. These potentials are listed in Table 1.

Because the current of 57 amperes was thought to be large for achieving these potentials, considering the extent of the underwater area, a test was performed with the ship's permanent anodes turned "off" and auxiliary anodes suspended from the pier at a minimum of 25 feet from the hull. The same amount of current was required from these anodes as from the ship's permanent anodes to produce the same potential on the hull. This indicated that current distribution from the permanent anodes was satisfactory and that the neoprene anode shields were in good condition. The conclusion concerning the anode shields was corroborated by periodic divers' inspections.

During a one day period in September, 1954, a number of potential readings were made under several different conditions. With the submarine tied up to the pier, the hull potential indicated by No. 9 reference electrode was 0.83 volt, with 55 amperes flowing from nine anodes at 5.8 volts. After the ship began to move, at 10 knots, the potential gradually decreased to 0.73 volts in four hours with the same current flowing. On submerging, the current increased to 65 amperes as a result of two additional anodes being under water. The potential of the hull in the vicinity of the reference electrodes ranged from 0.66 to 0.77 volt. When the ship returned to the pier and tied up, the No. 9 electrode read 0.77 volt. This value increased slowly and five hours later was 0.83.

Dry Dock Inspection—February 1955

On February 10, 1955, inspection of the ship on the marine railway at Key West showed that the hull was in excellent condition with the vinyl paint functioning well. The small areas that were bare of paint were almost completely free of corrosion. Only a few spots of superficial corrosion were found anywhere. Some coating was gone from the area surrounding the propeller but no corrosion was noted.

Of the eleven platinum anodes, three were damaged. Anode No. 3 was severed near the neoprene seal, apparently the result of a break in the cladding

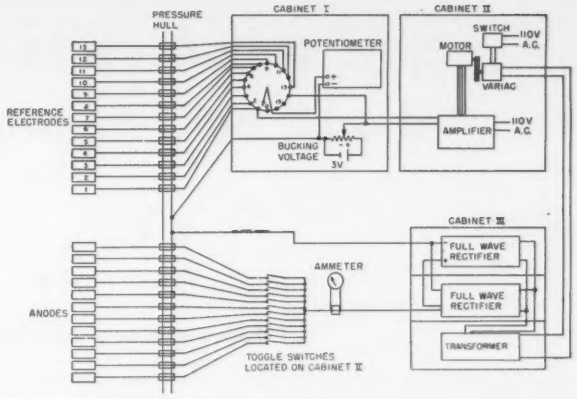

Figure 1—Wiring diagram of the cathodic protection system on submarine.

TABLE 1—Hull Potentials

Position	LOCATION	Volts
1	Near propeller—starboard	0.87
2	Near propeller—port	0.87
3	Amidships—starboard	0.82
4	Amidships—port	0.80
5	Bow—starboard	0.78
6	Bow—port	0.79

Note: Current was 57 amperes. The reading on the permanently installed reference electrode No. 9 was 0.83 at this time.

with subsequent anodic corrosion of the copper core. One-third of anode No. 10 and two-thirds of anode No. 11 were gone. Since these anodes were still able to supply current when tested just prior to the dry docking, efforts were made to seal the open ends. Eight anodes remained undamaged.

The neoprene cable seals appeared to be completely free of any damage resulting from the 10 months' exposure to sea water and chlorine. The lucite sleeves used to support and insulate the anode rod showed no change from their original appearance. Likewise, no damage of any kind to the sheet neoprene shield was noticed.

Some Observations from the Initial Installation

The anodes of the original installation consisted of 12 copper rods, ¼ inch in diameter and 2 inches long, clad with 0.005 inch of platinum-palladium alloy. It was intended to make use of the high current density permissible from a platinum surface in sea water to furnish a relatively large amount of current from a small anode area. Operating for one year at a current density of four amperes per square inch caused no noticeable deterioration of the platinum. However, while the high current density did not affect the platinum, it appeared that a sufficiently high concentration of chlorine was produced so that some damage resulted to the neoprene seal that protected the junction between the anodes and the copper cable. The vinyl paint that was used as a shield around the anodes was also damaged by the chlorine flowing upward from the anodes.

An additional consideration in the use of the small anodes was their relatively high resistance. Operating with nine anodes in 15 ohm-cm sea water, 18

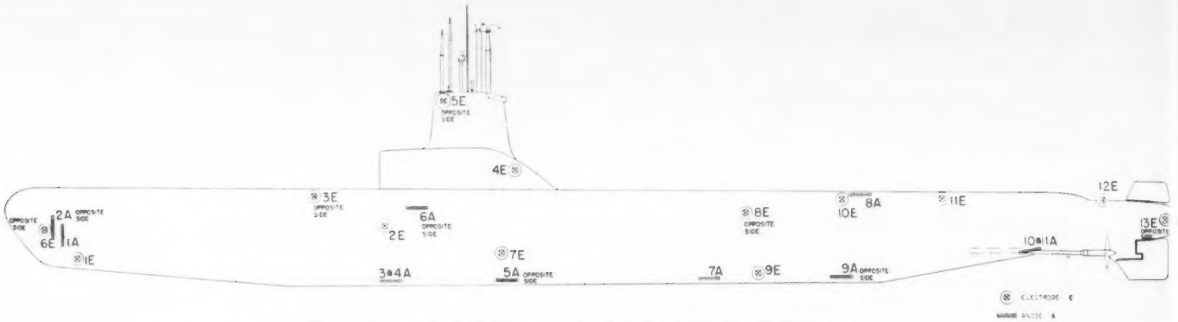

Figure 2—Location of anodes and reference electrodes on submarine.

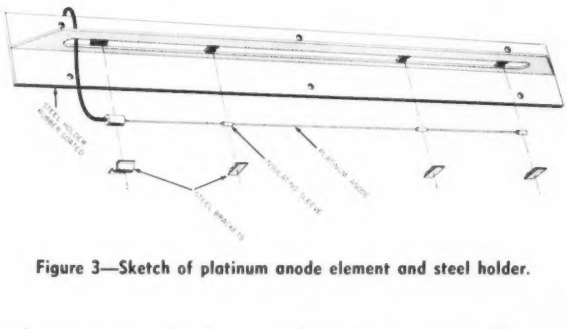

Figure 3—Sketch of platinum anode element and steel holder.

volts were required to produce 40 amperes. It was to avoid these difficulties that the modified system was equipped with longer anodes and neoprene shields.

Since 40 amperes produced only a slight polarization, a test was performed with auxiliary anodes suspended from a pier at a minimum distance of 25 feet from the hull. Since the current required to polarize the hull to 0.85 volts was 120 amperes, it was concluded that the "cold plastic" paint system used on this ship was acting as a poor electrical insulation. Hence vinyl paint was used in the modified system.

Summary and Conclusions

A cathodic protection system using platinum anodes was on a submarine for nearly a year, a sufficient period of time to furnish certain useful and reliable data. The use of platinum anodes appears economically feasible inasmuch as the cost of these anodes constitutes a small part of the total cost of the installation. Furthermore, since platinum is apparently a completely inert anode material under the conditions of operation some economic gain can be expected from extended anode life.

Small platinum anodes were found to function at high current density without apparent damage to the platinum but they had a high resistance that was considered objectionable. In addition, the high current density at the anodes resulted in a concentration of chlorine in the surrounding sea water which damaged the neoprene cable insulation and the hull paint coating.

These disadvantages disappear with the use of large platinum anodes. The optimum use of such anodes, however, requires some further attention to mechanical design to avoid breakage.

On the basis of laboratory tests, it has been recommended that silver rods replace copper as the core material of the platinum anodes. In the event of a perforation of the platinum cladding the silver should corrode much less rapidly because of the protection provided by the silver chloride that forms. Tests at this laboratory have shown good results when a silver core was intentionally exposed to salt water.

Author's Note

The opinions expressed in this paper are those of the author and not necessarily those of the Naval Research Laboratory or of the Navy Department.

Appendix

Requests have been received concerning the construction of the silver-silver chloride reference electrodes. The method used in fabricating the cells for the work covered in the paper is here presented.

Rectangles measuring 2 inches by 6 inches were cut from high purity silver gauze of 20 mesh and 0.012 inch gauge. A 5-inch length of No. 16 gauge high purity silver wire was used as an electrical lead. It was placed along the 2 inch edge of the gauze, heated to a slight redness with a torch, and struck with a hammer. The element then had the appearance of a flag. The silver mesh was then rolled around the silver lead wire.

Next the gauze was cleaned by boiling in 20 percent sodium hydroxide solution for two hours, followed by three rinses in tap water and two rinses in distilled water. The element was then dried overnight in an oven at 100 C.

Silver chloride was heated in a silver crucible to approximately 50 degrees C above its melting temperature (455 C). The silver gauze was immersed in the molten silver chloride long enough for wetting to take place. The excess silver chloride was shaken out and after cooling, the silver-silver chloride element was made a cathode in a 3.5 percent sodium chloride bath. One-hundred ma was passed for one hour using a platinum anode.

When the elements are first put into use, there is usually a drift in potential for several hours. After this initial period the potentials of elements are stable and agree within 3 mv of one another. With the size of elements described here, it has been found that a current of 0.2 ma through the element continuously for 24 hours produced only a slight polarization.

Any discussion of this article not published above will appear in the June, 1957 issue.

Cathodic Protection of an Active Ship Using A Trailing Platinum-Clad Anode*

By H. S. PREISER and F. E. COOK

Introduction

CURRENT DISTRIBUTION in cathodic protection systems is dependent on several factors, the more important of which are driving potential, anode and cathode geometry, spacing between anode and cathode and the conductivity of the electrolyte. When designing cathodic protection systems for the underbody of active vessels, the corrosion engineer is plagued with the problem of achieving uniform current densities with anodes mounted directly on the hull. The consistent high conductivity of open sea water is favorable toward good distribution of current. The corrosion engineer has wide control over the geometry of the anode and the driving potential of the system, but he is seriously limited with respect to the spacing between the anode and the cathode.

Schemes in Use

Several anode configurations and arrangements have been advocated and tried in order to circumvent the problem of current distribution. In one installation on a Yard Tug Boat (YTB), thirty 12-inch x 6-inch x 1¼-inch zinc anodes were widely spaced around the hull. This arrangement proved successful in achieving balanced potentials over the hull surface.[1] In another installation, magnesium anodes (higher driving potential than zinc) were grouped on the bilge keel and insulated from the hull except through a rheostat control.[2,3] The current output was controlled to produce reasonably uniform polarization over the hull.

Other investigators have had success in spreading current by the use of high-potential, impressed-current anodes which were mounted on dielectric shields extending for several feet on each side of the anode.[4,5] The anodes, relatively few in number, were widely spaced along the hull. This shielding provides virtually the same effect as removing the anode a finite distance from the hull.

Shepard and Graeser[6] have shown that resistance to ground increases logarithmically as anode to cathode distance is increased. The curve becomes asymptotic to a fixed resistance value where anode to cathode distance is greater than 500 anode diameters. In general, shielding removes the anode from the cathode but at a distance, considerably less than 500 diameters. Therefore, although shields reduce high current concentration and current wastage at the cathode in the immediate vicinity of the anode, optimum current distribution to an irregularly shaped cathode can be accomplished only by spacing the anode a remote distance away from the cathode.

Another important consideration is that length to diameter ratio of the anode geometry is a large factor in reducing the resistance of an anode located a re-

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Abstract

A high capacity versatile trailing platinum-clad anode has been developed and tested. When trailed behind the stern of a moving ship, a uniform polarization pattern was achieved at speeds up to nine knots. Uniform polarization also was achieved with the ship at rest and the anode in a remote position.

The current requirements for the ship polarized between —0.80 and —0.85 volt (to silver-silver chloride) ranged from 5 amperes at rest to 15 amperes at 9 knots. The current requirements under velocity conditions were higher for the unpolarized hull than for the hull pre-polarized at rest.

The driving voltage versus current output of the anode was determined for a range up to 47 amperes. The measured remote resistance of the anode to the hull (ground) was found to be in substantial agreement with calculated values.

The paper discusses the advantages of the trailing anode over existing hull-mounted anode systems, and speculates as to its future possibilities in the marine field. **8.9.5.**

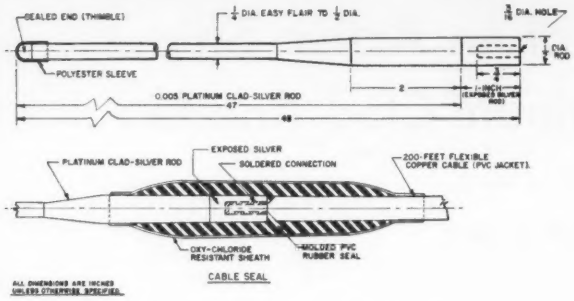

Figure 1—Trailing platinum-clad anode.

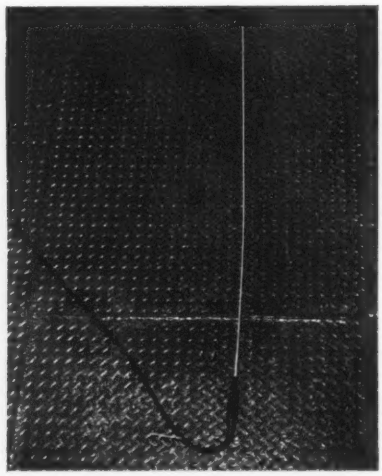

Figure 2—Over-all view of platinum-clad anode. Note moulded rubber cable connection.

mote distance to ground. An anode 48 inches in length and ¼-inch in diameter (ratio of 196 : 1) has an electrolytic resistance to remote ground of about 0.2 ohm when calculated by Dwight's formula.[6]

Engineering Penalty

All of these methods in use today, without exception, impose an engineering penalty on a cathodic protection system. Large masses of galvanic anodes in addition to economic aspects, increase dead weight carried and add to the frictional drag of the ship. Resistance controlled outputs from magnesium anodes decrease the anodic corrosion efficiency and therefore waste valuable anode material. High potentials generally destroy intact paint films and thereby increase current requirements to protect the ship. Applying dielectric shield materials around high-potential anodes, if properly done, is expensive and time consuming. In general, hull mounted cathodic protection systems require multiple anode assemblies fitted to the ship while in drydock. The system cannot be adequately inspected or maintained during service which is inconvenient and costly, if not operable.

Difficulties Overcome

The difficulties of installation and maintenance of a cathodic protection system on a ship's hull as well as the variations in performance can be overcome by using a trailing anode. By removing the anodes from the hull proper and consolidating them into one lightweight, streamlined, high capacity anode, one can trail such an anode a sufficient distance from the hull to give remote resistance to ground. This produces essentially uniform current paths to all parts of the hull. Edison[7] had tried to design such an anode but failed due to the lack of proper materials. Today with the knowledge of platinum-cladding and special cable sealing techniques, a simple high capacity, trailing inert anode is feasible, and practical.

Description of the Trailing Anode

The trailing anode consists of a single 90-10 platinum-palladium alloy cladding on a coin-silver rod, 48 inches in length. Other materials may be used in place of silver.

The major portion of the anode is a section ¼ inch in diameter which flares gradually to ½-inch diameter at one end. The cable attachment and insulated connection is made at the flared end in a streamlined manner. The other end of the anode rod is pressure capped with a platinum alloy thimble which is sweated in place with silver solder. A polyester resin sleeve is molded on the thimble end for further protection of the joint. The 5 mil cladding is tested anodically in a 3 percent NaCl solution at high current drain for 24 hours and by immersion in concentrated nitric acid for 48 hours to be sure that it is absolutely pore free. Figure 1 shows a schematic arrangement of the anode and cable seal and Figure 2 is a photograph of the over-all anode.

The cable is a PVC-sheathed, flexible single conductor about 200 feet in length which is attached by silver soldering to the silver rod. For continuous rugged duty, a steel cored insulated copper cable may be substituted for the stranded copper type.

A streamlined PVC rubber seal is molded over the cable and platinum-clad rod at the junction. The seal is then wrapped in polyethylene tape or sheathed in an oxy-chloride resistant material. For purposes of the experiment described herein the seal was made of a cast epoxy resin which in turn was sheathed by a PVC molded rubber skin.

The total calculated resistance of the anode rod to remote ground, which included the 200 feet of line resistance (0.2 ohm), was in the order of 0.4 ohm which was confirmed by plotting data of driving voltage versus current output of the anode in operation (see Figure 3).

Certain design considerations are involved in order to obtain a trailing anode which can be smoothly towed through the water without whipping, twisting or bobbing. If the anode is made an extension of the towing cable by designing the weight per foot of the rod to approach that of the cable and so as not to have any abrupt change in cross section, it will tow at a fixed depth for a given speed of the vessel.[8] Varying the speed of the vessel will cause the anode to seek a new steady depth. No flexing will occur at the cable connection and whipping will be absent

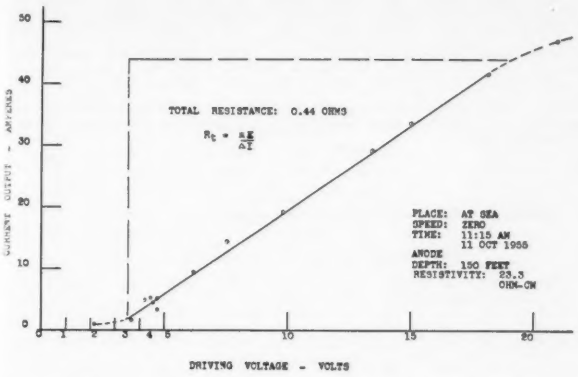

Figure 3—Current output versus driving voltage for trailing platinum-clad anode.

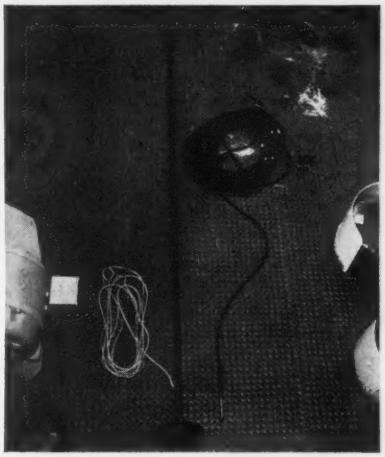

Figure 4—Disc (left) and trailing (right) Ag-AgCl reference electrodes.

because of a smooth axial flow pattern associated with fluid flow over a cylindrical section.

Early Experiments

In February, 1955, the first attempt was made to polarize an active Yard Tug Boat, YTB 366, with the trailing platinum anode.[9] Unfortunately for this experiment the zinc anodes normally installed on the stern of the tug boat had been renewed in January, 1955, and the potential of the hull before applying current averaged about —0.78 volt.[1] The results of applying current from a trailing anode to this ship showed that it took only 2.1 amperes to polarize the hull to —0.85 volt at the dockside and 4.2 amperes underway at 12 knots. The potential of —0.85 volt was arbitrarily chosen as the level of complete protection. In actual practice, polarization to —0.82 volt is more than adequate.

The YTB 366 has an approximate underwater area of 1800 square feet and a manganese bronze propeller of about 90 square feet. Since the original potential data showed considerable polarization of the hull prior to applying current from the trailing anode, the test was not considered adequate. Preparations were made to run this test again using an unpolarized ship.

Later Experiments

During the early part of October, 1955, another ship was available for repeating the experiment.[10] This work boat had a length over-all of 64 feet, beam of 18 feet and full-load draft of 6 feet 2 inches. Its wetted surface was computed at 1065 square feet and its manganese-bronze propeller area at 21.8 square feet. The ship had been last painted with a Navy cold plastic paint system in 1954 and dockside observations revealed moderate fouling on the bottom.

Installation

The ship was outfitted with four silver-silver chloride reference electrodes. Two stationary disc-type reference electrodes were suspended on pipe supports and tied to the hull, one forward on starboard side, the other aft on port side. In addition, two trailing reference electrodes were arranged at the stern on 50 foot cable leads. Figure 4 shows an over-all view of the two types of reference electrodes used.

The trailing anode was attached to the stern on a 200 foot lead of cable. Figure 5 shows the schematic arrangement of the reference electrodes and trailing anode.

The reference electrode leads were brought into a selector switch which in turn was connected to a potentiometer-voltmeter instrument. The trailing platinum-clad anode was connected to the ship's service DC generators through a large capacity variable resistance bank.

Dockside Tests

First Test

On 6 October 1955 a preliminary test was made. Purpose of the test was to determine polarization and depolarization response time of the ship with current impressed from a platinum-clad anode located remotely.

The vessel had an initial potential of —0.62 volt. A current of 10 amperes at a driving voltage of 4.6 volts was applied from the trailing anode suspended 200 feet away from the ship. The closed circuit potential of the hull climbed to —0.85 volts in 30 minutes and dropped off rapidly when the circuit was opened. Figure 6 is a plot of these potentials against time.

A current of 10 amperes produced a rapid polarization response of the hull which indicated that the current supplied was in excess of that normally required. Temporary polarization was achieved as indicated, by the rapid depolarization of the hull which followed when the current from the anode was turned off.

Second Test

On 10 October 1955 another dockside test was

[1] All hull potentials are open circuit potentials and refer to the saturated silver-silver chloride half-cell in seawater. In this paper the potentials increase in the anodic direction (more negative) and decrease in the cathodic direction (less negative).

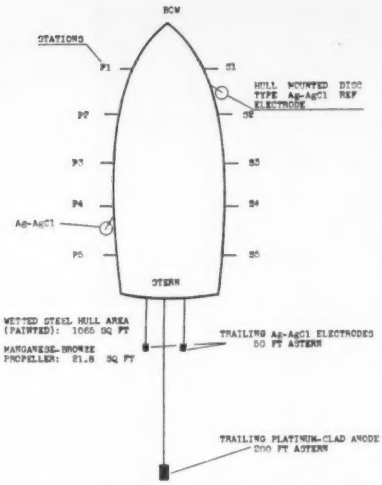

Figure 5—Schematic arrangement of trailing the platinum-clad anode from the ship.

TABLE 1—Dockside Hull Potential Survey

Electrode Depth	Readings in Volts at Various Stations[1]											
	Bow	S1	S2	S3	S4	S5	Stern	P5	P4	P3	P2	P1
Water Line	0.66	0.68	0.69	0.68	0.68	0.67	0.67	0.67	0.67	0.67	0.67	0.66
6 Feet	0.66	0.66	0.68	0.68	0.68	0.67	0.66	0.67	0.67	0.67	0.67	0.67
12 Feet	0.66	0.67	0.68	0.68	0.68	0.67	0.66	0.67	0.68	0.67	0.67	0.67

Note: Time of survey was 9:15 pm, 10 October, 1955; resistivity of sea water was 25.5 ohm-cm at 52 F; Reference Electrode was Ag-AgCl.
[1] Minus Sign Omitted.

TABLE 2—Hull Potential Survey at Sea

Electrode Depth	Readings in Volts at Various Stations[1]											
	Bow	S1	S2	S3	S4	S5	Stern	P5	P4	P3	P2	P1
Waterline	0.72	0.72	0.72	0.74	0.73	0.71	0.69	0.72	0.73	0.72	0.73	0.70
6 Feet	0.74	0.72	0.74	0.73	0.73	0.71	0.70	0.72	0.73	0.73	0.72	0.71
12 Feet	0.74	0.73	0.74	0.73	0.73	0.71	0.71	0.72	0.73	0.73	0.72	0.71

Note: Time of survey was 10:35 am, 11 October, 1955; resistivity of sea water was 23.3 ohm-CM at 53.5 F; Reference Electrode was Ag-AgCl
[1] Minus Sign Omitted.

conducted. Purpose of this test was to determine the current requirements to polarize the hull to the open-circuit potential of —0.82 volt under stationary conditions.

The ship was electrically isolated from the dock by disconnecting all shore power and outside telephone circuits. Manila line and camels (rope fenders) were used to moor the ship to the dock. At first a hull potential survey was made at various stations around the hull as marked in Figure 5. Table 1 lists the hull potentials measured at various stations which averaged about —0.67 volt. The uniformity of the observed hull potentials indicated partial polarization of the propeller by the hull or by the remaining zincs which were attached to the hull. The trailing anode was again located about 200 feet from the hull and suspended vertically in the water by tying the electrical lead to one of the dock pilings.

A water sample was taken and analyzed. The results showed a pH of 7.5, specific gravity at 77 F of 1.025 and a salinity of 3.7 percent. The resistivity calculated at 52 F was 25.5 ohm-cm.

This time by careful adjustment of the current over a period of about 10 hours, 6 amperes were found to maintain on open circuit a hull potential of —0.85 volt. A plot of potential versus time (average of bow and stern electrodes) recorded during the run is shown in Figure 7. Battery power from the ship's generator starting system was used to supply current for this dockside test.

The current required to maintain an open circuit polarization of —0.82 volt on the stationary ship was in the order of 5 amperes. The slow depolarization which occurred when the current was turned off indicated that a more permanent polarization film was achieved on a hull when the time of polarization was increased.

The hull potentials were measured with reference electrodes mounted close to the hull. Reading with a remote reference electrode indicated a higher potential by 50 millivolts. A check between two reference electrodes spaced about 75 feet apart while current was flowing from the trailing anode revealed an IR drop of .05 volt in the sea water circuit which accounts for the difference between adjacent and remote reference electrode readings. The same difference was recorded during underway tests.

Sea Trials

Current from the dockside trials was turned off at 7 AM the next day and the ship was made ready for sea. The anode was reconnected directly to the ship's service generator switchboard. At 10:30 AM the ship "lay to" (i.e., the ship was brought into the wind and held stationary except for drifting) about 5 miles offshore where the water depth was about 200 feet. The ship had depolarized gradually, but the 3½ hour time interval with no current from the anode did not allow complete depolarization of the hull.

Prior to running a new series of tests, another hull potential survey was taken in the "lay to" condition which is tabulated in Table 2. A sea water sample was taken and analyzed. The resistivity was calculated to be 23.3 ohm-cm at 53.5 F.

Purpose of Tests

Tests were conducted to measure the relationship between the driving voltage and current output of the trailing anode located a remote distance from the hull. The trailing anode was connected to the ship's generator and was suspended vertically from the stern 150 feet below the keel.

The current was varied from 1.0 to 47.0 amperes, the maximum capacity of the resistor bank. Figure 3 is a graph of the results. It can be seen that the major portion of the curve is linear, the slope of which is equal to the resistance of the anode. Note that no current flowed until the back voltage of the anode was overcome which was in the order to 2.0 volts. Furthermore, the upper end of the curve is beginning to flatten out which may have been the result of a gas film resistance created by the turbu-

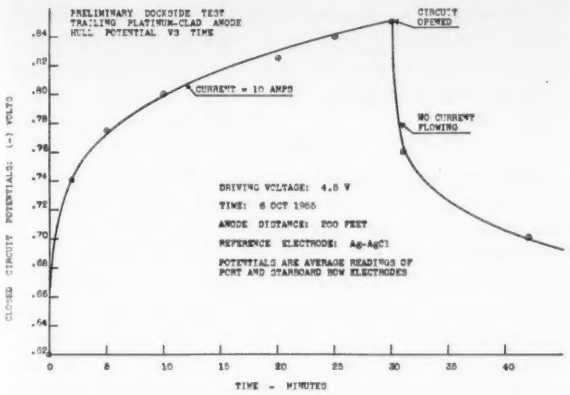
PRELIMINARY DOCKSIDE TEST
TRAILING PLATINUM-CLAD ANODE
HULL POTENTIAL VS TIME
CIRCUIT OPENED
CURRENT = 10 AMPS
NO CURRENT FLOWING
DRIVING VOLTAGE: 4.8 V
TIME: 6 OCT 1955
ANODE DISTANCE: 200 FEET
REFERENCE ELECTRODE: Ag-AgCl
POTENTIALS ARE AVERAGE READINGS OF PORT AND STARBOARD BOW ELECTRODES
CLOSED CIRCUIT POTENTIALS: (-) VOLTS
TIME - MINUTES

Figure 6—Hull potential versus time on preliminary test with a trailing platinum-clad anode.

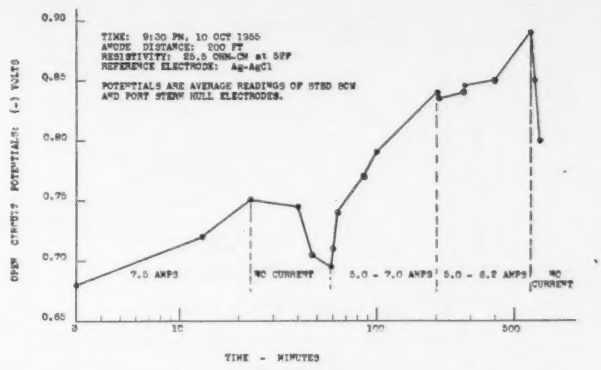
TIME: 9:30 PM, 10 OCT 1955
ANODE DISTANCE: 200 FT
RESISTIVITY: 25.3 OHM-CM at 58F
REFERENCE ELECTRODE: Ag-AgCl
POTENTIALS ARE AVERAGE READINGS OF STBD BOW AND PORT STERN HULL ELECTRODES.
OPEN CIRCUIT POTENTIALS: (-) VOLTS
7.5 AMPS
NO CURRENT
5.0 - 7.0 AMPS
5.0 - 8.2 AMPS
NO CURRENT
TIME - MINUTES

Figure 7—Hull potential versus time on final dockside test with a trailing platinum-clad anode.

lent bubbling (oxygen and chlorine) at the anode. No attempt was made to determine the practical maximum current output that could be realized from the trailing platinum-clad anode.

Conclusions

The current output was essentially linear and averaged about 2.5 amperes per volt over the 18 volt range of the test.

During this test which consumed 30 minutes, the open circuit hull potential rose from about —0.70 to —0.89 volt. The current was then dropped to 5 amperes and held for one hour. The hull potential remained constant at about —0.80 volt which further confirmed the conclusions of the second dockside test. The anode depth was varied next from the 150 foot submergence to the surface in increments of 50 feet over a period of five minutes to determine if the hull potential would be affected. No change of current output, driving voltage or hull potential was noted during the brief period in which the anode to cathode distance was varied. Apparently, longer period tests are necessary to establish the change in hull potential distribution with anode distance to hull.

Underway Tests

Purpose of Tests

Tests were conducted to determine the effect of ship's speed on the current required to maintain a protective polarization of —0.82 volt.

A series of potential and current readings were made with the ship underway. The data are shown in Figure 8. The anode was trailed at 200 feet and two additional electrodes were trailed at 50 feet. Starting at zero time, a current of about 5 amperes maintained an average hull potential of —0.79 volt at three knots.[2] Four minutes later, the ship's speed was increased to six knots; the current setting was not changed. During the ensuing 19 minute period, the open circuit potential dropped from —0.79 to

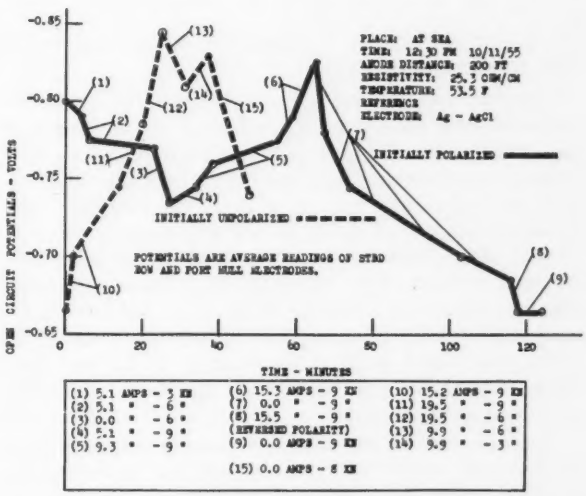
PLACE: AT SEA
TIME: 12:30 PM 10/11/55
ANODE DISTANCE: 200 FT
RESISTIVITY: 25.3 OHM/CM
TEMPERATURE: 53.5 F
REFERENCE ELECTRODE: Ag - AgCl
INITIALLY POLARIZED
INITIALLY UNPOLARIZED
POTENTIALS ARE AVERAGE READINGS OF STBD BOW AND PORT HULL ELECTRODES.
OPEN CIRCUIT POTENTIALS - VOLTS
TIME - MINUTES
(1) 5.1 AMPS - 3 HR
(2) 5.1 " - 6 "
(3) 0.0 " - 6 "
(4) 5.1 " - 9 "
(5) 9.3 " - 9 "
(6) 15.3 AMPS - 9 HR
(7) 0.0 " - 9 "
(8) 15.5 " - 9 "
(REVERSED POLARITY)
(9) 0.0 AMPS - 9 HR
(15) 0.0 AMPS - 8 HR
(10) 15.2 AMPS - 9 HR
(11) 19.5 " - 9 "
(12) 19.5 " - 6 "
(13) 9.9 " - 6 "
(14) 9.9 " - 3 "

Figure 8—Underway tests with a trailing platinum-clad anode. Hull potential versus time is shown for various operating conditions.

—0.77 volt. The speed was then increased to nine knots but due to a power failure for four minutes, the potential dropped to —0.735 volt. Power was restored and the current was increased to nine amperes and held for 21 minutes. The hull potential rose to —0.75 volt at the stern and —0.80 at the bow averaging to —0.775 volt. The current was increased once again—to 15 amperes; after 10 minutes, the bow potential rose to —0.85 and the stern to —0.80 volt. The average potential of —0.825 is plotted in Figure 8.

The current was then turned off and a speed of nine knots was maintained. In about 50 minutes, the hull potential dropped to an average of —0.685 volt. In order to depolarize the hull further, the current leads were reversed; the hull was made the anode and the trailing platinum rod the cathode.

After a two minute reversed current shot at 15 amperes, the leads were reconnected in the normal manner. The open circuit potential dropped to an average of —0.665 volt. No further depolarization was observed during the following six minutes where

[2] Average potential is the arithmetic mean of the bow and stern hull mounted electrodes. The trailing remote electrodes were used as check stations and in all cases, read about 50 millivolts higher than the average.

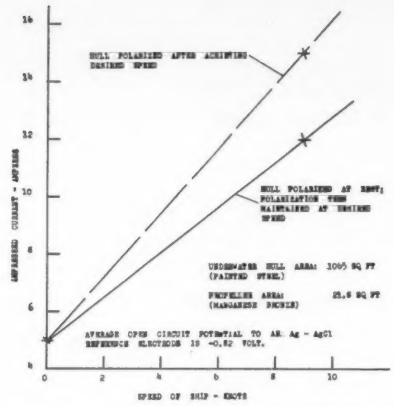
HULL POLARIZED AFTER ACHIEVING DESIRED SPEED
HULL POLARIZED AT REST; POLARIZATION THEN MAINTAINED AT DESIRED SPEED
UNDERWATER HULL AREA: 3065 SQ FT (PAINTED STEEL)
PROPELLER AREA: 25.6 SQ FT (MANGANESE BRONZE)
AVERAGE OPEN CIRCUIT POTENTIAL TO AN Ag - AgCl REFERENCE ELECTRODE IS -0.82 VOLT.
APPLIED CURRENT - AMPERES
SPEED OF SHIP - KNOTS

Figure 9—Approximate current required to polarize ship's hull versus speed of ship when using a trailing platinum-clad anode.

the speed of the ship was maintained at nine knots and no current applied.

Current was applied again at 15 amperes. After 14 minutes, the hull potential climbed to an average of —0.745 volt. The current was then raised to 19.5 amperes and after an elapsed time of six minutes the hull potential reached an average of —0.785 volt. Slowing the vessel down to six knots made the potential climb to —0.845 volt at 19.5 amperes of impressed current. The current was reduced to about 10 amperes and the average potential settled to —0.81 volt in about six minutes. The speed was reduced to three knots and current maintained at 10 amperes. This caused the hull potentials to climb to —0.83 volt within six minutes.

An estimate of the average current requirements to maintain —.082 volt open circuit hull potential at various velocities is shown on Figure 9.

Conclusions

On a pre-polarized ship, the current required to maintain polarization at the speed of nine knots was a little more than twice the current required for the ship at rest. The current required to polarize the ship travelling at a speed of nine knots (unpolarized at rest) was three times the current required for polarization under stationary conditions.

The trailing anode and trailing electrode operated satisfactorily at speeds up to nine knots with no whip or vibration. No visible damage occurred to the anode when operated at current outputs up to 47 amperes.

Summary and Conclusions

The trailing platinum anode has demonstrated its ability to cathodically protect a small ship with comparative simplicity in port and at sea. Uniform polarization of the hull was achieved with a current output of five amperes with the ship at rest and 12 amperes when underway at nine knots. Platinum anodes remain clean in service and do not build up resistant films on their surface as evidenced by the linear relationship between current output and driving voltage. The ease of trailing the platinum anode under service conditions and its high current handling capacity make this type of system easily adaptable to larger ships.

Discussion

The trailing platinum-clad anode should find application on naval and commercial ships. It may not be well suited for high-speed warships operating and maneuvering in convoy stations but it should lend itself to naval auxiliaries and merchantmen.

The upper limit of current output for a trailing platinum-clad anode is dictated only by its dimensions and the driving voltage available. It is believed to be the least expensive and most versatile cathodic protection system known for an active ship and its installation and maintenance is relatively simple to achieve.

The cost of a trailing anode cathodic protection system for a 100 ampere current capacity (capable of protecting an ocean-going cargo ship) should not exceed $1,000. The same capacity system using hull mounted anodes[11] will exceed this cost by at least a factor of 10. The expected life of the platinum-clad trailing anode, barring mechanical destruction should be greater than the service life of the ship.

Future Plans

Further tests are planned at sea with larger and faster ships to determine the anode's effectiveness in polarizing greater hull areas and to determine the anode trailing characteristics at higher speeds. Should these tests prove successful, plans will be drawn up to have the anode trail from an access pipe fitted through the hull and be retrieved automatically.

Acknowledgments

The technical assistance in the performance of the experiment and the writing of the two test reports[9,10] by the Scientific Test Section of Code 251B of Portsmouth Naval Shipyard are gratefully acknowledged. The experiments were performed by J. J. Jackson, L. A. Belletete and D. E. Lincoln under the general supervision of E. C. Taylor, R. C. Whitman and R. L. Fortier. The opinions expressed in this article are those of the authors and do not necessarily reflect the official views of the Navy Department.

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Any discussion of this article not published above will appear in the June, 1957 issue.

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Casing Corrosion in the Petroleum Industry*

By JACK L. BATTLE*

Abstract

The failure of production string casing as a result of corrosion in wells of the petroleum industry is rapidly becoming one of the most serious and perplexing problems to confront the industry. With the period of flush production behind the industry in many areas and more pronounced emphasis being placed on prolonged production under secondary recovery methods, practical solutions to this problem are being sought.

This paper points out those areas in which the problem of casing corrosion is most troublesome, and lists the generally accepted causes and means of preventing and repairing such failures. The more recently developed methods of investigation, such as the use of casing potential logs and current withdrawal-potential surveys, and the use of cathodic protection for preventing failures are discussed. **8.4.3**

Introduction

AT THE END of 1954 there were 514,808 producing oil and gas wells within the United States. These wells produced 2,312,212,000 barrels of oil, or 12.3 barrels per well per calendar day, during the year. Almost 60 percent of these wells were discovered more than 15 years ago, and about 50 percent were more than 20 years old.[1] Until recently little consideration was given to the possible failure of the production casing string. This seems rather strange considering that this thin-walled member, the purpose of which is to maintain the originally drilled hole for the productive life of the well, is the most important structural member of the well.

At the original high production rates and the anticipated rapid depletion of the reservoirs in the early history of the oil industry, the engineer may have been justified in giving little consideration to corrosion failure of the casing. But with the advent of proration, application of more scientific production methods and increased emphasis on secondary recovery methods, all of which have been resorted to with the intent of prolonging the productive life and increasing the ultimate recovery from oil fields, failure by casing corrosion has become a problem of serious concern to the oil industry.

A recent survey was conducted by NACE Subcommittee T-1H on Oil String Casing Corrosion in which 14 major company representatives participated. The survey indicated that in 30 fields (51,462 wells) in which these companies operated, a total of 235 casing failures occurred during the three-year period 1949-51. Repair of these 235 wells cost the operators $1,343,317. If the same failure frequency is assumed to have occurred among the nonparticipating companies in the fields covered, the number of failures may be estimated at 1,294 and the cost of repairs at 7½ million dollars. This figure does not include the cost of loss of production or the possible loss resulting from the premature abandonment of a well which could not be profitably redrilled at today's drilling cost. Obviously, a solution to the problem of casing corrosion will have an important bearing on the cost of producing oil in the future.

Causative Factors

Failure of casing as a result of corrosion is not a matter of considerable surprise to the corrosion engineer. As a matter of fact, thoughtful consideration of the many environmental factors involved leads one to wonder how the casing could last as long as it does. In general, the failure of oil string casing usually is attributed to one or more of the following causes:

External Causes:

1. Bacterial attack.
2. Contact with formations of varying mineral and fluid content.
3. Electrolysis caused by stray and subsurface electrical currents.
4. Galvanic action caused by the presence of dissimilar metals in close proximity.
5. Metallurgical defects in casing.

Internal Causes:

1. Vapor space attack by acidic gases (hydrogen sulfide and carbon dioxide).
2. Fluid zone attack by acid waters.
3. Corrosive gas-lift gas.
4. Atmospheric oxygen intrusion.
5. Unspent acid from acidizing operations.
6. Erosion by sand and fluid.
7. Mechanical damage in drilling and completion.

Table 1 gives the results of the NACE subcommittee's survey. It shows aggressive fresh water, formation salt water, and acidic gases to have been the most frequent causes of failure in the 235 cases reported, with stray currents not far behind. More recent developments indicate bacterial attack is a far more significant causative factor than originally thought. Hadley[2] was among the early pioneers in recognizing the significance of microbiological corrosion. His works, as well as those of Starkey and Wight,[3] Bastin et al,[4] and Beerstecher,[5] provide a thorough discussion of the subject.

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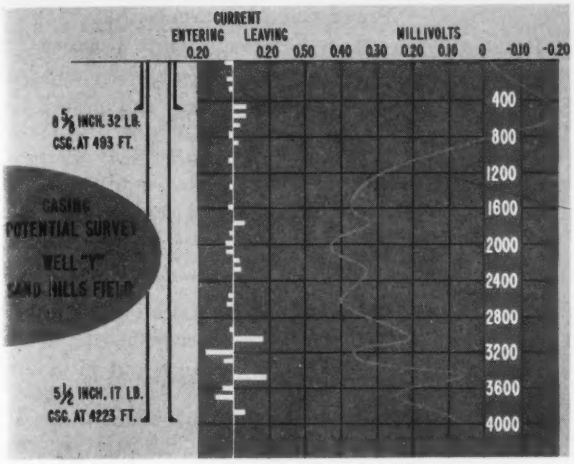

Figure 1—Casing potential survey of Well "Y".

TABLE 1—Report of National Association of Corrosion Engineers Committee T-1H on Oil String Casing Corrosion

Reported Cause of Failure	Number	Percent
Stray current	37	16
Acidic fresh waters	83	35
Acidic gases in vapor zone	44	19
Bacterial attack	9	4
Salt water (formation)	46	20
Unknown	10	4
Other	6	2

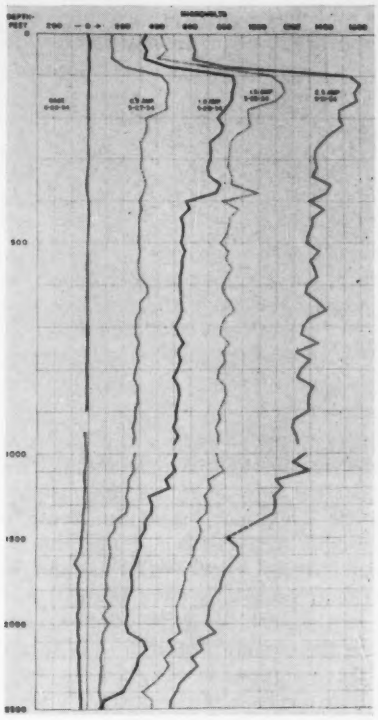

Figure 2—Potential profile log of Well "X".

Methods of Investigation

In most cases the corrosion engineer is confronted with the necessity of analyzing the cause of casing failure without ever examining the failed member. Unless failure occurs at a rather shallow depth, recovery of failed pipe for examination and study is usually impossible. Consequently, the corrosion engineer must rely on other means to evaluate the cause of failure and to base recommendations for remedial and preventive measures. He has at his disposal the following commonly used methods of investigation:

1. Chemical analysis of produced waters and correlation with waters from known sources.
2. Chemical analysis of produced gases.
3. Packer tests to locate depth of failure.
4. Casing caliper surveys to determine depth and extent of internal corrosion.
5. Flow line current surveys to determine if surface currents are a contributing factor.

Casing Potential Log

More recently, additional methods of investigation have been suggested and have come into rather widespread use. Possibly the most important of these is the casing potential log. This is a log obtained by measuring the potential drop over definite lengths of casing to determine the direction and magnitude of current flow in the casing member. Ewing[6] was among the first to use and publish the results of an investigation using such a tool.

Tools used for making casing potential logs may be either single or multiple contact. In running the log, the logging tool is run into the well to maximum logging depth on an insulated conductor cable. The tool is then stopped, the knife-blade contacts made to contact the casing, and potential measured. The measurement is made between the contact and the surface in the case of the single-electrode tool, and between two or more contacts at fixed distances apart (usually 10, 20, 25, or 50 feet) in the case of the multiple-contact tools. Obviously the potentials measured in the latter case are much smaller than those obtained in the case of the single electrode, and more sensitive instrumentation is required because the potentials measured are usually in microvolts. Using the measured resistivity calculated from the mass resistivity of steel, the magnitude of current flow can be calculated with reasonable accuracy.

Advantages of Multiple-Contact Tool

Advantages of the multiple-contact tool over the single-contact tool have been discussed by Ewing and Bayhi.[6] The most important advantages are:

1. Each tool reading indicates the current in the measured interval only and is not superimposed on the drop above the electrode.
2. As the contacts are only 10 to 50 feet apart, thermal effects are negligible.
3. The leads are parallel and similar in length, thus balancing out extraneous effects.

The difficulty of penetrating dense, adherent water scales, corrosion products and paraffin deposits is common to both the single and multiple-contact in-

struments and may constitute a source of error. The multiple contact instrument has the disadvantage of requiring extremely sensitive potentiometers or vacuum tube voltmeters.

Figures 1 and 2 show logs obtained by single and multiple contact tools in wells in the East Texas and West Texas fields, respectively. Figure 1 presents the log obtained by single-contact tool in a well in the Sand Hills Field of West Texas. It reveals anodic areas, as shown by the bar-graph, at 500 and 600 feet, the former depth approximately coinciding with the depth at which the surface casing string was set, and at depths of 3,100 and 3,500 feet. Casing leaks developed at 3,119 and 3,314 feet some 14 years after completion of the well and were repaired by squeeze cementing.

Figure 2 presents the log obtained by a multiple-contact tool in the East Texas Field. The base log indicates current flow of minor magnitude down the casing to the 2,500-foot maximum depth of the log with no anodic areas shown. Since the majority of the casing failures experienced in the field occur above 500 feet, such logs have been of minor aid in the study of the problem in this field except to aid in determining the current required to render the casing cathodic. Investigations designed to evaluate the anodic kick at the base of the surface pipe under conditions of current withdrawal have minimized the possibility of casing failure at this point. It is believed that with proper care and interpretation, either type of log can be used to considerable advantage in interpreting subsurface currents.

Current-Potential Curve

Another method which, although first reported by Britton[7] in 1931, has come into use recently as a means of determining the required current drainage rate for cathodic protection is the current-potential curve. The semi-log plotting of potential with respect to a reference electrode versus the impressed current on a corroding member shows a break in the curve at the impressed current rate required for protection.

Figure 3 shows a typical potential-current curve obtained on a well in the East Texas Field. This technique uses the Pearson-Hadley null current circuit and requires the use of a vacuum tube voltmeter for reliable application. By means of either of these methods, rectifier or magnesium anode installations for cathodic protection of casing may be designed by qualified engineers for permanent or long-life protection. Thus, cathodic protection provides considerable promise as a possible means of eliminating external casing corrosion. Sudbury, Landers, and Shock,[8] however, as well as others, have called attention to possible dangers resulting from the transfer of impressed current from the oil string to the surface pipe. Such a transfer of current might cause accelerated corrosion of the oil string casing at that point. Recent examination of a string of 7-inch OD, 24-pound casing recovered from a well in the East Texas Field, from which had been withdrawn 10 amperes for a period of some seven months, failed to indicate any damage to the oil string at the base of the surface pipe.

Preventive Measures

Preventive measures most commonly practiced at the present time are as follows:

1. The installation of insulating flanges at the wellhead.
2. Intermittent oil coverage.
3. The use of volatile or nonvolatile inhibitors where annulus seals by means of packers or fluid can be obtained.
4. The placement of highly alkaline muds at points of possible or known serious attack.
5. The application of cathodic protection.
6. The placement of gel-type materials of an inorganic or organic nature.
7. The use of protective coatings (or cement).

Insulating Flanges

The installation of insulating flanges to isolate the wellhead and subsurface equipment from the flow line in order to eliminate surface stray currents has been very effective in many fields. Hammond and Ewing[9] report a remarkable reduction in the number of failures at Loudon, while another operator reports a reduction in casing failure frequency of 75 and 60 percent in the Talco and Tomball fields, respectively. This measure is less effective where soil resistivities are extremely low or where electrolysis is the result of subsurface currents.

Protective Coatings

The use of protective coatings has been given little consideration because of the obvious difficulties of application to pipe in place and the possibility of mechanical damage to the coating when installing new pipe. Evaluation would also present a difficult problem. Cementing of casing to the surface or up into the new larger string should be effective if complete coverage can be obtained.

Highly Alkaline Drilling Fluids

The placement of highly alkaline drilling fluids or gel-type materials has been reported in a number of fields. One operator has reported the pumping of highly alkaline "red" mud into the annulus of a number of wells in the East Texas Field. This measure will be discussed further below. This presents problems involving: (1) possible collapse of casing since the condition of the casing is unknown, and (2) the movement of the displaced or injected fluid to the proper point. Another operator has reported laboratory investigations to indicate that the organic gel-type materials commercially available at present provide an excellent culture medium for bacterial growth.

Inhibitors

The setting of packers and the loading of the annulus with alkaline fresh-water muds or nonvolatile inhibitors in crude oil is one of the most widely practiced measures to eliminate internal vapor or fluid-

zone attack from acid gases and waters. It is obviously an effective and fairly positive solution to the internal corrosion problem as long as packers may remain in the well. The intermittent or continuous lubrication of such inhibitors into the annulus of pumping wells also is widely practiced and effective. The use of volatile inhibitors such as anhydrous ammonia in the annulus of wells having fluid seals shows promise although details of lubrication need to be worked out.

Cathodic Protection

The use of cathodic protection to control external attack is receiving intense study by a number of operators at the present time. One operator reports its application using magnesium anodes to some 225 wells in one field in the West Texas area. Several other operators are experimenting with it in the East Texas Field. There is considerable question as to the maximum depth to which such measures are effective inasmuch as the operator has little control over variable formation resistivities. There is evidence to indicate, however, that cathodic protection can be obtained to a depth of 6,500 feet. Either rectifier or galvanic anodes may be used as the source of direct current.

Repair Procedures

Specific repair procedures will be discussed in connection with areal problems; however, a brief explanation of these techniques is believed desirable. The most commonly practiced procedures are:

1. The setting of a tubing packer.
2. The setting of an inside liner.
3. The placement of cement by squeezing.
4. The cutting and removal of damaged casing and replacement by means of casing bowl assembly.
5. The "backing off" of casing below point of failure and replacement by use of die-nipples.

Tubing Packer

The setting of a tubing packer below the point of leakage in the casing is the most economical method of correcting a casing failure. Unless complications arise, it normally can be accomplished for $1,000 per well or less; however, it is generally considered the least satisfactory method except for temporary repair. The point of failure is not sealed and corrosive fluids are admitted to the annulus to attack the tubing and packer element, which frequently leaks and admits the formation fluids to the producing well bore.

Inside Liner

The setting of an inside liner to total depth is practiced in certain areas where original casing size will permit. Unfortunately, 5½-inch casing was set in many wells as the production string, which obviously did not anticipate the later setting of an inner string of practical size. The setting of 4½-inch flush joint liner in such casing is the smallest size available through which normal production operations as now

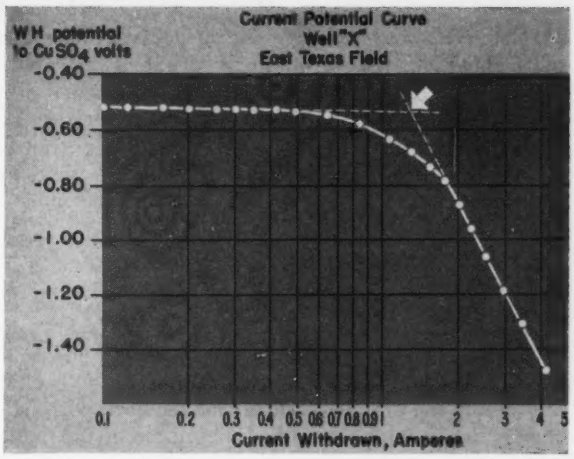

Figure 3—Current potential curve of Well "X".

TABLE 2—Areas in Which Casing Corrosion Occurred

AREA	Surface Attacked	Causative Agent
East Texas	External	Corrosive fresh water and bacterial attack
West Texas-New Mexico	Internal	Vapor zone attack by acidic gases
Magnolia, Arkansas	Internal	Vapor zone attack by acidic gases
Western Kansas	External	Contact with Dakota water sand
California (Ventura)	External	Bacterial attack

practiced may be conducted. The cost of running an inside liner varies, of course, with depth and availability of steel but may cost anywhere from $5,000 to $35,000. More recently the setting of partial liner strings has been practiced to seal leaks, but the cost of such operations frequently approaches the cost of setting a liner to total depth.

Cement by Squeezing

The cementing of a casing leak by squeeze methods merely involves the placement of cement at the point of failure by a method which restricts its application to a certain portion of the formation. By the application of pressure, the cement is forced into the point of failure and into the formation. Thus, the failed portion of casing is surrounded by a sheath of cement. This is the most frequently used and successful method of repair and is usually accomplished at a cost of $3,500 to $7,500, depending upon the number of stages required to obtain a shut-off.

Replacement by Means of Casing Bowl

The replacement of the damaged casing with new pipe using the casing bowl or patch tool assembly involves the setting of a plug below the point of failure. It also involves the mechanical cutting of the casing below the point of damage, its recovery, and the rerunning of new pipe with the patch tool designed to locate and slip over the remaining portion of the casing in the hole.

A seal between the new and old casing members is made by means of casing slip and pack-off element, which leaves the casing without internal obstruction for future production operations. This method is pre-

ferred by some operators, although it is slightly more expensive than squeeze cementing because there is a more positive repair obtained. This is the only method which permits recovery of the corroded casing for visual examination. The cost of such a repair again varies with the depth of the leak but currently repairs are being made in the East Texas Field by several operators at cost of $3,750 to $4,300 exclusive of the pipe used.

"Backing Off"

A more recently developed method of repair which is receiving considerable attention in the East Texas Field involves the use of an inside casing slip tool. With this tool casing may be unscrewed or "backed off" below the point of failure and replaced with new casing run in with a modified die-nipple, if the depth of failure is not too great. This technique has shown considerable promise of reducing the cost of casing repairs within the East Texas Field to approximately $2,500 per well.

Areal Problems

Committee studies have indicated five general geographic areas where casing corrosion is a matter of more than general concern. The areas are listed in Table 2.

Each of these areas presents a problem serious in magnitude. The West Texas-New Mexico and the Magnolia, Arkansas, areas present very similar problems involving sour crudes, while the other three areas present widely different characteristics.

East Texas Area

A recent survey in the East Texas Field showed that 80 percent of all casing failures on which the depths of failure were known to have occurred were above 400 feet and 62 percent between 200 and 325 feet. The most serious corrosive attack occurred over an interval of 50 to 75 feet. There is some disagreement among the various operators as to the most significant causative factor. A corrosive fresh-water sand is known to exist, however, over the major portion of the field at a depth of 150 to 300 feet. This water contains approximately 100 parts per million total solids. It has relatively high iron and carbon dioxide contents, and possesses a pH value of 5 to 6 immediately after being produced at the surface.

A ferrous sulfide slime has been observed on the affected areas of casing, indicating the presence of bacterial action. Flowline current surveys and casing potential logs have not shown any significant surface or subsurface currents. In general, it is believed an attempt to fix a single causative factor would result in oversimplification. It is quite likely that all three factors are involved, but at this time bacterial action appears to be most significant. Repair has involved setting packers, squeeze cementing, cutting and pulling the casing and replacing it by the use of the casing bowl and the running of inside liners where casing size limitation permitted.

On the assumption that the corrosion can be arrested by isolation of the casing from contact with the corrosive fresh waters, one operator has placed highly alkaline mud behind the casing in five wells to a depth below the zone where the leaks normally occur. This also should prevent bacterial attack. To evaluate the effectiveness of this method of control, the wells were selected in areas where numerous casing leaks had occurred. Two of the wells have now been abandoned and the casing recovered and inspected. A slight increase in the normal pH of the adhering mud was observed but the highly alkaline mud had apparently migrated into the formation and had not stopped bacterial activity on the pipe. The principal operational problem observed in the placement of mud in the wells has been difficulty experienced in pumping the mud to a sufficient depth to provide protection from corrosion throughout the interval susceptible to casing leaks. A small rotary pump capable of pumping against a head of 150 pounds per square inch was used to pump the mud behind the casing, displacing the existing well fluids to the formation. In those instances in which this pressure was insufficient to pump the mud behind the casing, a tubing packer was set in the well and a balance pressure applied to prevent collapse of the casing as the mud was placed with a reciprocating pump. While sufficient pressure was obtained in this manner, loss of mud to shallow formations has prevented the mud from reaching the desired depth on two jobs. It is estimated that the placement of the highly alkaline mud behind the casing could be accomplished at a cost of $200 per well. The procedure which has been used on the five jobs performed to date has included the tracing of the mud with a radioactive tracer and gamma ray logging instrument as it is pumped behind the casing. Consequently, the cost of these experimental jobs has been approximately $700 per well.

Cathodic protection is receiving serious consideration by a number of operators in the area as a possible preventive measure. Initial installations are now being made and will be watched with interest.

West Texas-New Mexico Area

Casing failures have become so widespread in the West Texas-New Mexico areas in recent years that both the production operator and state regulatory bodies have become quite concerned. Investigations disclosed that casing failures were widespread in the Adair, Block 31, Hobbs, Levelland, Means, Seminole, Slaughter, and Wasson fields. The production of many of the wells in these fields is limited by capacity, so that any downtime results in loss of oil. One company estimated, on the basis of repair and workover experience, that in excess of $5,000,000 would be spent on their wells alone if no preventive measures were adopted.

Cooperative study by the producing companies has eliminated galvanic action as the major cause of failure. Correlation of external pit depth versus casing potential logs has indicated excellent agreement in that most subsurface currents were shown to leave the casing immediately below the surface string setting but very few cases of complete perforation in that area have been reported. In fact, the majority

of casing strings which have been pulled have shown little evidence of external attack.

With the possible exception of one field in the area, no evidence of bacterial attack has been observed. Casing caliper surveys and visual inspection of pipe recovered have demonstrated that the major attack is confined to the vapor space of the wells. It is thought that corrosion results from condensation of moisture on the cool wall of the casing opposite water sands in the presence of the acidic gases, carbon dioxide and hydrogen sulfide. The acidity of the condensed water is believed to be a function of the acid gas concentrations and the total pressure in the annular space. Several major operators are attempting to correlate acid gas pressure history and corrosion damage in wells in this area. Preliminary work has been encouraging and possibly a suitable basis for specification of corrosion preventive program may result.

The most widely accepted program of prevention at the present time involves the setting of tubing packers and the loading of the annulus with water-free crude oil containing one or two gallons of inhibitor per 100 barrels of oil. A second method which shows promise is the lubrication of volatile inhibitors such as anhydrous or aqueous ammonia into the annulus of those wells in which there is a fluid seal.

One operator has reported the presence of ammonia vapor in the annular space up to nine months after a batch lubrication of the chemical. The continuous and intermittent lubrication of absorptive- and wetting-type inhibitors is practiced by some operators in pumping and gas-lift wells. This method has the advantage of providing protection to both the casing and the tubing, but there is no ready means of determining the degree of protection obtained through use of this or the volatile inhibitor other than failure records, a slow and time-consuming method.

Repair of failures is accomplished by one of three methods: (1) squeezing the leak with cement or plastic, (2) setting an inner string of smaller diameter pipe, or (3) cutting and pulling the corroded section of casing and rerunning a new section and attaching to the old string by means of a casing bowl or patch.

The first method is the most generally practiced procedure although, due to the poor condition of the pipe, additional holes may be created by the application of pressure. The setting of an inside string of casing is often impossible in many wells because they were originally cased with 5½-inch pipe.

The third method is somewhat hazardous because of the original abnormal well bore enlargement through the thick salt section prevalent in the Permian Basin area. In many instances no allowances were made for this enlargement in original calculations of cement requirements for setting intermediate and oil strings; consequently, many of these strings remain in place under varying degrees of tension and compression with horizontal support through much of the salt section. Casing failures occurring in the enlarged bore through this section, resulting in complete severance of the casing, may result in misalignment of the free end of the pipe when the tubing is pulled. In this event, abandonment of the well or redrilling, if economics permits, is indicated. Normally, however, repair is accomplished by the setting of inner strings and cementing to the surface.

The average cost of setting a packer in wells in the area is $1,000, while cost of repair of a casing failure averages $25,000 unless complications arise.

Magnolia, Arkansas Area

Casing failures in the Magnolia, Arkansas, sour crude area are very similar to those in the West Texas-New Mexico area and have been thoroughly discussed by Bailey and Crowell.[10]

Western Kansas Area

In the Kansas and Illinois area, casing failures have been abnormally high under two particular conditions. Numerous failures have occurred, as in the West Texas-New Mexico area, from internal attack of acid gas in the vapor zone in the Bemis-Shutts and Iuki-Carmi fields of Kansas. An even greater number of failures have occurred at rather shallow depths as a result of external attack of casing by aggressive waters in the Dakota sand section in the Trapp, Dorr, Kreuger, and Morel fields. These failures are usually repaired by squeezing cement at an average cost of $3,000. Cathodic protection is being applied by many operators in the area.

California Area

Doig and Wachter[11] have fully described failures in the Ventura Field, California. After extensive investigation and elimination of other causative factors, they attributed failure to bacterial corrosion. Certain species of bacteria, presumably of the sulfate-reducing variety, have been isolated in the corrosion products in contact with the casing. Since highly alkaline environments are known to stifle bacterial activity, the use of highly alkaline muds in the drilling of all new wells was adopted as standard practice to prevent future failures. This, however, does not provide a solution to the prevention of bacterial corrosion in existing wells.

Other Areas

One operator recently has reported an abnormal number of casing failures in the Colorado Field of Jim Hogg County, in the lower Texas-Gulf Coast area. This is a development which is believed to add additional significance to the importance of microbiological corrosion. This field was discovered in 1939 and produces from the Cockfield sand at a depth of approximately 3,200 feet. It is a solution gas-drive sand and produces a sweet crude of 46 degrees API gravity with little or no salt water. This particular company operates 118 pumping wells in the field and a pilot water flood project has been initiated in the southern portion of the field.

To date, nine casing failures have occurred at depths of 1,450 to 1,550 feet. Flow line current surveys and casing potential logs have ruled out the possibility of surface or subsurface currents.

On recent abandonment of one of the wells, an attempt was made to recover the casing to a depth

of 1,600 feet for examination. Unfortunately only 1,128 feet (28 joints) was recovered, the top 1,050 feet of which was pulled dry. The casing was in essentially new condition internally. Externally, except for the first four joints, it was covered with an almost dry ¼-inch thick cake of greenish-black slime in which ferrous sulfide was present; the presence of sulfate-reducing bacteria was confirmed by laboratory examination. Removal of the slime revealed corrosion damage characteristic of that resulting from sulfate-reducing bacteria.

Suggested Procedures to Prevent Failures

Casing corrosion must be examined from the standpoint of well control and safety with due consideration for the economics involved. Every effort should be made to detect casing leaks early in the life of a field and corrective or preventive measures adopted before existing metal is lost. For the benefit of the practicing corrosion engineer who is confronted with the problem of casing corrosion, the following suggestions are offered.

1. Evaluate the corrosive characteristics of a new field in the early life of the field in order that suitable mud and cementing programs, from a corrosion standpoint, can be adopted.
2. Install insulating flanges in the flow lines of all new wells completed as producers unless previous surveys in that field have indicated such flanges are unnecessary.
3. Install insulating flanges in all wells in old fields in which flow line current surveys and the remaining reserves of the field indicate such action would be economical.
4. If casing recovery is obtained in areas where corrosion failures of casing have occurred, have a qualified corrosion engineer present to examine the casing at the well site immediately following its recovery from the well bore.
5. Make full use of volatile and nonvolatile inhibitors in wells known to be corrosive.
6. Examine all recovered subsurface equipment thoroughly for corrosion and maintain complete description and cost data on damaged equipment.
7. Eliminate the use of perforated tubing couplings, and orifice buttons as a means of production in every instance possible. Consideration should be given to the incorporation of reverse check valves in all gas-lift valves.

Conclusions

The seriousness of the problem of corrosion of production string casing in oil and gas wells has only recently been recognized. The causes of corrosion failure can be recognized in most cases by a thorough study of the environmental factors. Adequate "tools" are available for studying the casing corrosion problem except for the lack of a proven device for determining the condition of the outside of the casing in place. Certain corrosion preventive measures apparently have minimized losses in many fields. These measures include appropriately planned mud and cementing programs, the use of inhibitors for protecting the inside of casing, and the use of insulating flanges to minimize the flow of surface electric currents. Obviously, much work remains to be done in the application of cathodic protection and the placement of highly alkaline fluids as preventive measures.

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Measurement of the Instantaneous Corrosion Rate By Means of Polarization Data*

By R. V. SKOLD and T. E. LARSON***

Introduction

THERE HAS BEEN considerable attention focused lately upon the need for reducing the degree of corrosion taking place in water distribution lines. The annual expenditures for power costs, necessitated by loss in carrying capacity, as well as for cleaning and replacement as a result of tuberculation within the lines is on occasion exorbitant. In order to decrease the corrosion of pipe lines, the fundamental corrosion factors are being studied, the water characteristics are being investigated and inhibitors are being evaluated so that corrective measures may be taken.

One of the initial objectives[1] of this study was to determine an adequate measure at a particular time of the corrosion rate in "fresh water" mineralization which would be applicable both as a laboratory and field measurement. For this purpose, preliminary studies were made on changes in specimen potentials resulting during corrosion (potential-time studies), and changes on specimen potentials caused by externally applied current (polarization studies).

Apparatus and Testing Equipment

The apparatus used in these studies was the same as that described by other investigators.[2,3] This apparatus supplied a constant velocity-total immersion testing of the specimens. The specimens tested were principally 1½ x 3 inch sections of 0.01 inch "black plate" steel free from mill scale. Machined cast iron specimens also were tested. All specimens had holes drilled near the top edge to facilitate connection of an electrical test lead.

Cleaning of the specimens prior to use involved the following procedure:

1. Degreasing in carbon tetrachloride
2. Preliminary acid cleaning in a 5 percent solution of HCl and HNO_3 for two minutes
3. Acid cleaning in concentrated HCl for one minute
4. Neutralizing in 1-N Na_2CO_3 solution for one-half minute
5. Rinsing in distilled water for one minute
6. Rinsing in acetone.

The specimens were then dried and stored in a vacuum dessicator for a minimum of 48 hours. Immediately prior to use, the specimens were attached to the electrical test leads which also served as specimen holders, and the electrical contacts and the edges of the specimens were coated with paraffin wax. The velocity of motion furnished by the apparatus was 0.085 and 0.14 foot per second. All tests were conducted at room temperature.

The total dissolved solids content and quality of the waters were varied over a considerable range but essentially most of those studied were with waters similar in anion content and in total dissolved solids

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Abstract

The use of polarization data in the measurement of instantaneous corrosion rates is described. Steel and cast iron specimens were tested in 3000 ohm-cm waters; potentials were measured by a multicombination meter.

Potential-time studies were made on all specimens in order to determine any relationship which such studies might have to the corrosion rate. It was found that a limited empirical quantitative relationship exists between the polarization slope, $\Delta E/\Delta I$, at low current density and the corrosion rate as measured by weight loss. Such a relationship will permit a rapid empirical determination of the corrosion rates of metal specimens while they are immersed in a fresh-water environment.

The effect of pH on the corrosion rate of mild steel is considered briefly. **2.3.5**

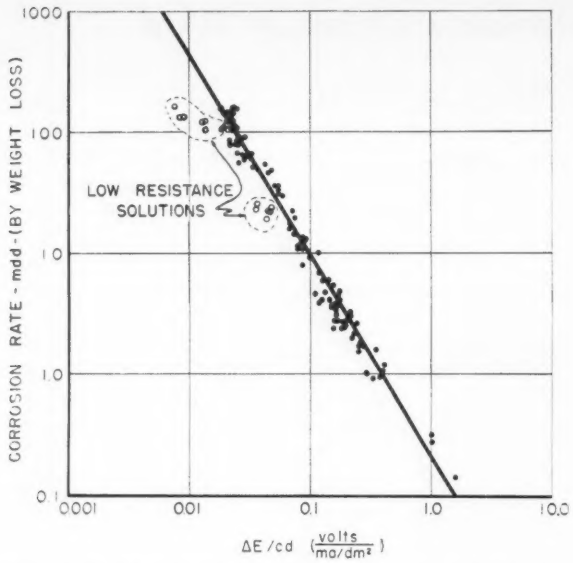

Figure 1—Empirical relation between initial slope of polarization curve (resistance) and corrosion rate determined by weight loss.

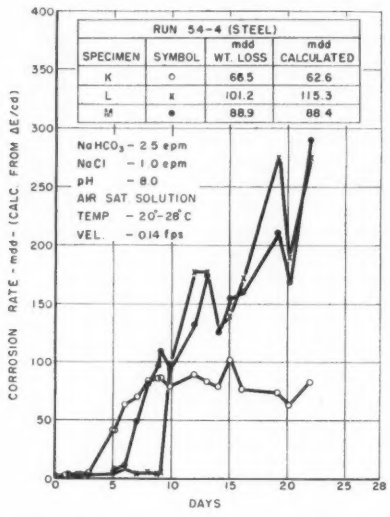

Figure 2—Corrosion rate variation with time for Run 54-4.

to Great Lakes water. The usual specific resistance of the water was about 3,000 ohm-cm. The salts consisted primarily of $NaHCO_3$ and NaCl. The pH of the solutions were usually 7.0 and 8.0, maintained by carbon dioxide. In one study the pH was varied from 6.0 to 8.5. Constant dissolved oxygen was maintained by continuous diffusion with air. Each jar with three metal specimens in each was maintained at 18 liters of solution by a constant level apparatus.

Potentials were measured by a multicombination meter (W. C. Miller, Model B-3). Applied current was measured by the ammeter portion of a Weston Circuit Tester Model No. 785 having ranges of 0-50 microamps, and 0-1 milliamp. Current was supplied by a Type C dry cell battery, and was regulated by a variable resistance in the external circuit.

A saturated calomel reference electrode for measuring the potentials was fastened to the side of the test jars approximately three to six inches from the specimens. A double-faced platinum electrode was used for application of current to the specimen. This electrode was fastened by a clip to the specimen holder so that each face of the platinum electrode was approximately one-half inch away from the surface of the specimen.

Preliminary Electrical Measurements

The potential-time studies confirmed observations by others[4] that a particular specimen potential was not related in any way to the corrosion rate.

Complete polarization studies were made in order to calculate corrosion rates from the initial "breaks" in the polarization curves according to the work of Pearson,[5] Schwerdtfeger and McDorman[6] and others. This type of study was abandoned for several reasons: (1) the "breaks" in the polarization curves were not sharp enough to allow sufficient accuracy in the calculation of corrosion rates, (2) the collection of data was very time consuming, and (3) the applied current, especially in high amounts, often increased the subsequent rate of corrosion.

Polarization At Low Applied Current

One characteristic of the polarization studies was that polarization potential appeared to be a straight line function of the applied cathodic and anodic currents at low current density. It had been noted that the slope of this line, $\Delta E/\Delta I$, was higher for a specimen having a low corrosion rate than for one having a high corrosion rate. Simmons[7] corroborated this observation in a study on evaluation of inhibitors. His experiments indicated that there may be a quantitative relationship between the $\Delta E/\Delta I$ slope and the weight loss tests.

Such a measure of the corrosion rate was desirable, since it would require only small amounts of applied current and would therefore probably not affect the local cell polarization equilibrium and could be determined in a relatively short period of time.

Results of the $\Delta E/\Delta I$ Slope Determination

To establish the anticipated relationship between $\Delta E/\Delta I$ and the corrosion rate calculated from weight loss data, several measures of $\Delta E/\Delta I$ were made on each specimen, each day that it was exposed to the corrosion environment. To place each determination on an equivalent basis, the $\Delta E/\Delta I$ was converted to ΔE/c.d. (the change in potential per unit applied current density). In order to relate the weight loss corrosion rate to ΔE/c.d. (volts/ma/dm²), a time average value of ΔE/c.d. was calculated. This resulted in an apparent logarithmic relation as shown in Figure 1.

Using this relationship, values were then obtained for the instantaneous corrosion rates. These instantaneous corrosion rates were then time-averaged to calculate an average corrosion rate for the period from which a value of ΔE/c.d. was obtained from the line in Figure 1. These corrected average values of ΔE/c.d. were then plotted against the weight loss

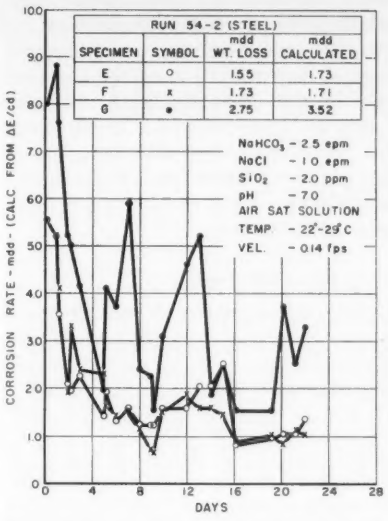
RUN 54-2 (STEEL)
SPECIMEN | SYMBOL | mdd WT. LOSS | mdd CALCULATED
E | ○ | 1.55 | 1.73
F | x | 1.73 | 1.71
G | • | 2.75 | 3.52
NaHCO3 - 2.5 epm
NaCl - 1.0 epm
SiO2 - 2.0 ppm
pH - 7.0
AIR SAT. SOLUTION
TEMP. - 22°-25°C
VEL. - 0.14 fps
CORROSION RATE - mdd - (CALC FROM ΔE/cd)
DAYS

Figure 3—Corrosion rate variation with time for Run 54-2.

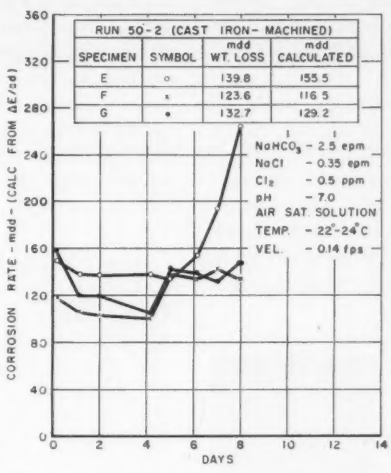
RUN 50-2 (CAST IRON- MACHINED)
SPECIMEN | SYMBOL | mdd WT. LOSS | mdd CALCULATED
E | ○ | 139.8 | 155.5
F | x | 123.6 | 116.5
G | • | 132.7 | 129.2
NaHCO3 - 2.5 epm
NaCl - 0.35 epm
Cl2 - 0.5 ppm
pH - 7.0
AIR SAT. SOLUTION
TEMP. - 22°-24°C
VEL. - 0.14 fps
CORROSION RATE - mdd - (CALC FROM ΔE/cd)
DAYS

Figure 4—Corrosion rate variation with time for Run 50-2.

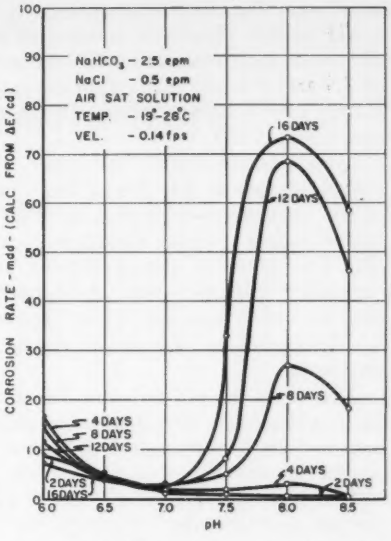

Figure 5—Effect of pH on corrosion rate.

corrosion rate. The points shown in Figure 1 relate to all such values as determined to date.

Figures 2-4 show actual tests on the instantaneous corrosion rate (mdd) versus the time exposed.

Figure 2 shows the typical results of specimens that have an initial resistance to corrosion that eventually breaks down with time of exposure to allow high rates of corrosion. The corrosion rate usually increased very sharply at the breakdown of the initial resistance to corrosion.

Figure 3 shows the instantaneous corrosion rates of specimens in a less aggressive environment. All three specimens indicate continually changing corrosion systems. Specimen G shows a greater variability with sharp increases and decreases in the corrosion rate.

Figure 4 shows the results with three machined cast iron specimens. With these specimens and with steel specimens in some environments there was little initial resistance to corrosion and the corrosion rate was high immediately.

That the corrosion rate is not a smoothly changing function for a particular specimen is indicated by the rather sharp increases and decreases in the corrosion rates. Since this occurs, a continuous measurement of the instantaneous corrosion rate would be required in order to determine a more exacting relationship between the instantaneous rate as measured by the slope of ΔE/c.d. and the rate as measured by weight loss. The intermittant measurements of ΔE/c.d. which were made therefore did not include many other variations in the corrosion rates between measurements. This in part accounts for the deviations from the line shown in Figure 1. The results tend to deviate by an average error of about 20 percent.

Another primary source of error results from the specific resistances of the various solutions. These do not significantly affect $\Delta E/\Delta I$ for specimens having low corrosion rates since the local cell resistances are large in comparison to the solution resistances. However, when the local cell resistances are very low as would be the case with a specimen having a high corrosion rate, the effect of the solution resistance may be a significant portion of the $\Delta E/\Delta I$ readings. This is demonstrated in Figure 1 by the points outlined in the dashed-lined sections which represent specimens immersed in solutions of lower resistance (350-850 ohm-cm). The fact that most of the solutions under test have similar ionic strength, 3000 ohm-cm, reduces much of the possible deviation. If greater accuracy were required the effect of solution resistance could possibly be determined. The accuracy at lower corrosion rates is limited by instrument sensitivity.

The potential lag behind the application of current was another possible source of error. To avoid this, the potential was considered stable after the potential reading had been constant for two minutes. The time for the potential to reach a steady state after each increment of applied current, varied from a few seconds for specimens with high corrosion rates to about 15 minutes for specimens with very low corrosion rates.

Application of the $\Delta E/\Delta I$ Determination of Corrosion Rates

Effect of pH on the Corrosion Rate of Mild Steel

Using the $\Delta E/\Delta I$ determination, the effect of pH on the corrosion rate of mild steel was studied at room temperature in aerated water containing 2.5 epm $NaHCO_3$ and 0.5 epm NaCl. The pH (6.0 to 8.5) was controlled by the continuous addition of CO_2. Measurements of $\Delta E/\Delta I$ were made each day to follow the course of the corrosion process. Figure 5 shows the results of this study, the calculated corrosion rate being plotted against pH with a series of curves for 2, 4, 8, 12 and 16 days of immersion at 0.14 foot per second. With the passage of time a

maximum corrosion rate appears to be established at a pH of 8.0. However, since the corrosion rates of the steel specimens are still increasing at pH values of 7.5 and 8.5, the maximum corrosion rate could be somewhere between these pH values and not necessarily at pH 8.0.

Luce and Fontana[8] indicated a similar peak of corrosion rate at pH 8.0 in their study of the effect of pH on erosion-corrosion of mild steel in "distilled water" using circular rotating discs at high velocity. The reluctance of the specimens at pH 8.5 to start corroding indicates that at higher pH values there may be little corrosion. There appears to be a tendency for the corrosion rate at pH above 8.5 to approach a minimum.

The rates at pH 6.5 and 7.0 are fairly constant. At a pH of 6.0, the corrosion rate reached a peak value of 16.8 mdd after 4 days, but decreased to 7.3 mdd at 16 days.

The average corrosion rates as determined by weight loss for the 17.2 days of immersion were: pH 6.0—10.0 mdd; pH 6.5—5.0 mdd; pH 7.0—2.6 mdd; pH 7.5—11.9 mdd; pH 8.0—49.9 mdd; pH 85—34.1 mdd.

In review of these data, the quality of water must be stressed. Considering the chloride-bicarbonate ratio, these results are in agreement with previous studies[1,3] which also show that higher chloride-bicarbonate ratios result in higher corrosion rates at pH 7. At lower chloride-bicarbonate ratios, equal or lower rates might be expected at pH 8 and 8.5. Thus the relation of pH to corrosion rate depends on the mineral composition of the environment.

Summary

A limited empirical quantitative relationship has been shown to exist between the polarization slope, $\Delta E/\Delta I$, at low current density and the corrosion rate as measured by weight loss. Such a relationship permits a rapid empirical determination of the corrosion rates and changes in the corrosion rates of metal specimens while they are immersed in a "fresh water" environment. The measurement of $\Delta E/\Delta I$ is an important aid in the study of the effect of changes in the corrosion environment, such as in the evaluation of the effectiveness of inhibitors.

Acknowledgment

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Lead Cable Sheath Corrosion Under Cathodic Protection Conditions*

By WALTER H. BRUCKNER and RAY M. WAINWRIGHT

Introduction

THE QUESTION of whether or not lead surfaces can corrode under cathodic conditions has received considerable attention in recent years. Although the use of bare lead as a final covering for underground electric power and communication cables may be giving way in favor of some kind of organic coating, there are still hundreds of millions of dollars invested in bare lead-sheathed cable now in service. In addition millions more are being spent each year for bare lead-sheathed cable replacements and additions. It is a recognized fact that lead *does* corrode when in soil or sea water environments, and it would be highly desirable in most instances if this corrosion could be eliminated by the normal cathodic protection techniques. For this reason any tendency of lead to corrode as a cathode is of major interest to corrosion control engineers.

In 1945 Halperin[1] summarized the field experiences and suggested that lead surfaces of cables did corrode under cathodic conditions, but only when sodium (or other) salts such as NaCl were present in the environment in significant amounts. Such salts, of course, were present in many instances in the winter when street de-icing was undertaken. Halperin theorized that the alkaline environment near the cathodic lead surface was caused by a build up of NaOH, and that the lead surface corroded by "sodium corrosion" under cathodic conditions, the weight loss taking place from conversion of the lead to the biplumbite through excess hydroxyl ions. Others holding similar views were Burns,[2] Hiers[3] and Mears and Brown.[4] Some theoretical work on possible reactions was done by Van Rysselberghe and others[5] in 1948, and various other physical chemists have done work on theoretical phases of the reaction problems since that time.

The later opinions of many physical chemists conflicted with the "sodium hydroxide" theories, and in 1953 Salzberg[6] tried to show that a lead hydride was formed at the lead surface. He also listed certain other possibilities but ruled them out for various reasons. In the same year Hall and Wainwright[7] reported on a series of experiments, one of which was designed to check Salzberg's results. However, no agreement was reached in the tests. In fact no laboratory test at that time could be devised which could reproduce in any way the typical corrosion pattern which was found in the field[8,9] and alleged to be

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Abstract

Laboratory tests were conducted to determine whether or not corrosion of lead cable sheath can occur under cathodic protection conditions. Some of the runs were made in cells containing the aqueous solutions of chlorides or chlorides and alkali while other tests were made with the lead cable sheaths in contact with soil saturated with the various solutions. The results from all of these tests indicated that no corrosion of the cable sheath occurred in any of these environments so long as the cathode was receiving protective current. It was found, however, that corrosion and pitting of lead cable sheath could occur when the protective current was interrupted. It was determined that the cathode products of previous cathodic protection constitute an environment for potentially serious corrosion at any time that the protective current ceases to flow to any part of the lead cable sheath. 5.2.1

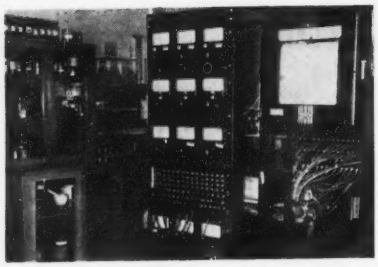

Figure 1—Cathodic Protection Laboratory in the Electrical Engineering Research Laboratory, University of Illinois. View shows power panel on the left and L and N six-point recorder on the right.

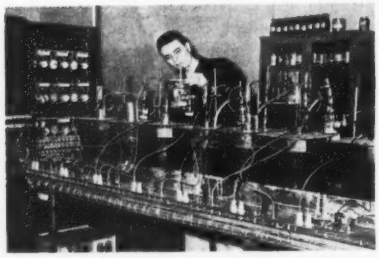

Figure 2—View shows cathodic protection cells with connection to current supply and potential measuring posts along one edge of the supporting table. At the left side are the back of L and N recording potentiometer and the current supply panel. Mercury-calomel half cells are shown on ring stands above the electrolytic cells.

the result of a combination of cathodic protection and de-icing salt conditions.

In 1955 Van Muylder and Pourbaix[10] working in Belgium obtained some conversion of lead to a colloidal state under intense cathodic protection conditions (from 30,000 to 200,000 ma/square foot) and with extremely high purity lead and precisely controlled solutions. That same year Markovic[11] claimed to have confirmed some of Salzberg's hydride theories, except that he found that the hydride formed remained on the surface, contrary to Salzberg's results.

In 1953 the Cathodic Protection Laboratory at the University of Illinois undertook to reproduce the corrosion pattern which was obtained on lead cables in the field, said to be under cathodic protection and in de-icing salt environments. The following discussion describes the facilities of the Cathodic Protection Laboratory at the University of Illinois, the tests conducted on lead cables under cathodic protection, and some preliminary conclusions concerning tests run to date.

Facilities

The Cathodic Protection Laboratory (referred to hereafter as CPL) at the University of Illionis is a co-operative venture started in 1950 by the Electrical Engineering Research Laboratory, in co-operation with the Engineering Experiment Station, the Department of Mining and Metallurgy, the Chemistry Department, and the Commonwealth Edison Company. Funds have come mainly from the Engineering Experiment Station, the Electrical Engineering Research Laboratory, the Commonwealth Edison Company, and the Northern Illinois Gas Company.

The facilities of the CPL include a special low-ripple, well-regulated, electronic power supply of 500 volts DC, 200 milliamperes capacity, feeding into 15 constant current sub-networks of the following ratings: three at 25 ma, five at 10 ma, five at either 5 ma or 1 ma, one at 200 microamperes, and one at 50 microamperes. Voltage outputs of the sub-networks were functions of the type of cell being tested and were independent of the currents. Each sub-network would feed at most three electrolytic cells in series. All wiring of potential measurement circuits was of 20,000 volts insulation to minimize leakage errors, and all other wiring was of 5,000 volts insulation rating.

The laboratory is presently operating a total of 18 separate cells in which cathodic protection may be applied to a system under observation. Probe voltage measurements of the cathodes or anodes may be continuously recorded on a L and N recording potentiometer for a maximum of six cells at one time.

At the left side of Figure 1 can be seen the power panel which contains the sub-networks with meters and the series of plugs and jacks required for cell circuit connections. On the right side of Figure 1 is shown the L and N six-point recorder and the wiring system required for recording selected cell potentials. Since the picture was taken, a panel has been added underneath the recorder from which "bucking" potentials are made available to permit recording a large range of cell potentials within the same scale range on the recorder. The recording potentiometer has an input impedance of 80 megohms, and a 400 mv scale, extendable to 2.4 volts by 200 mv steps.

Figure 2 shows a series of the cathodic protection cells connected to the current supply with potential measuring posts arranged along one edge of the supporting table. The back of the current supply panel and of the L and N recording potentiometer may be seen at the left side of Figure 2. Above the cells may be seen the mercury-calomel half-cells used with saturated KCl solution. The half-cells are connected to the potential measuring probes through vinyl tubing filled with saturated KCl solution. The pyrex glass potential probes are of special design, Pointelli-type, and have a 1 square millimeter opening, which is offset $\frac{1}{64}$-inch from the cathode surface when the probe tip makes contact with the electrode whose potential is to be probed. The glass portion of the probe and part of the vinyl tubing connection to the half-cell are filled with a warm saturated KCl solution to which about 3 percent of agar has been added. When this solution has been cooled to room temperature, it forms a gel which minimizes mutual contamination by diffusion of the probe content and the cathodic protection cell electrolyte.

In addition the laboratory is equipped with an analytical balance, pH measuring equipment, conductivity measuring equipment, vacuum apparatus,

low-temperature cabinet, and other normal laboratory equipment. Spectrographic analysis and x-ray diffraction equipment, photo-micrographic equipment, and other specialized apparatus are used from time to time from the departments of Chemistry and Metallurgy.

Testing Procedure

The testing procedure consisted in general of setting up laboratory type electrolytic cells in which the specimen of lead-sheathed cable could be placed and subjected to controlled environments with constant current densities on the surface of the lead, all necessary measurements being provided for. The cable specimens were of ⅞-inch OD single-conductor feeder cable, and 1⅞-inch OD three-conductor feeder cable, as supplied from stock by the Commonwealth Edison Company.

The cells in which the lead cable sheath specimens were placed under cathodic protection consisted of 9-inch OD pyrex jars, 12 inches high, which were each provided with nine flat, 3-inch x 11½-inch x ⅛-inch anodes of graphite. The anodes were arranged concentrically with the cathode, and the latter was placed at the center of the cell. For several runs, flat Duriron anodes were employed in the same manner as were the graphite anodes.

A lucite cover was provided for each of the 18 cells which served to lessen losses of cell electrolyte by evaporation and also served to hold a circular brass bus bar to which the anodes are fastened. The lead cathodes placed in the cells were arranged to project through a central hole in the lucite cover. Current leads were soldered directly to the end of the lead sheath projecting out of the lucite cover.

The area of the cathodes in contact with the electrolyte was restricted by covering the entire cathode, except for a circumferential strip of the desired width. A highly effective covering was obtained by using a single, spiral wrapping of "Scotchrap" polyvinyl pipe insulation tape.

Some of the cells were operated with soil solution extract to which chlorides were added, either singly or as a mixture. The chlorides used were K, Na, Ca and Mg. Other cells were operated with soil in contact with both electrodes, the soil being saturated with the desired chloride solutions. Still other cells were operated with KOH-KCl or NaOH-NaCl solutions with high pH values between 12 and 13. Table 1 gives the specific conditions of each test and the results therefrom.

The present testing procedure used may be described as one which evolved from the results of more than one year of previous testing. Specifically, the results of numerous past tests of lead cable sheath as cathode material under a variety of conditions indicated without a doubt that corrosion did *not* occur when the sheath was receiving protective current. But inasmuch as service experience has shown that failure by corrosion *does* occur on cathodically protected cable sheath, the research effort was directed to means other than, or in conjunction with, cathodic protection which would make it possible to duplicate in the laboratory the corrosion experienced in the field.

As shown in Table 1 intermittent tests of various types were instituted for the purpose of determining the conditions of prior cathodic protection which would produce corrosion of maximum severity with the deliberate cessation of cathodic protection. The intermittent tests are being continued in order to obtain complete data on conditions for maximum severity of corrosion.

A few tests also have been made on the effects of alternating current alone and of alternating current superimposed on a cathodic protection system. These tests are not described in Table 1 and have not gone far enough as yet to warrant presentation of results.

It shoulld be noted that all lead cathodes placed under protection in the CPL were operated at constant current. The Hewlett-Packard power unit which was used for supply of direct current, with a 500 volt maximum DC supply voltage, assured the maintenance of constant current even when cathode films and crusts of high resistance were formed. In practice, however, it is usual to operate a cathodic protection system in the field such that surface film potentials are less than five volts. In such cases the formation of high resistance films at the cathodes could effectively decrease protective current.

Test Results

The description of test conditions for series 6-55 to 16-55 tests are given in Table 1. A brief description of the cathode appearance at the end of the run is given in the last column of Table 1. In general the notation in this column is that corrosion did not occur during continuous cathodic protection. There was evidence under highly alkaline initial test conditions of the formation of slight or severe pitting of the cathode surface during intermittent cathodic protection, the cathodes remaining in the cell during the period of open circuit. The most severe pitting occurred when cathodic protection was intermittent and the lead cathodes remained in the highly alkaline solution for one week before re-applying cathodic protection.

For the tests made with chloride solutions, which were not made highly alkaline as an initial test condition, the results of intermittent tests indicated little evidence of corrosion except at the interface of air and electrolyte. At this point there was some evidence of corrosion of the cable sheath when insulating "Scotchrap" was not used in this area. However, even under continuous cathodic protection there is some indication of a slight attack in this area just above the liquid line. This is a region which receives little or no cathodic protection.

Weight loss tests on thin sheets of lead and cable sheath alloy were made prior to the tests given in Table 1. The data from these "miniature" tests were substantially the same as indicated in Table 1 (e.g., there was no loss due to corrosion during continuous cathodic protection.)

As a general observation it should be noted that for the tests shown in Table 1, a thick, hard, adherent

TABLE 1—Cathodic Protection—Tests on Lead Sheathed Cable

Series and Number	Conditions	Duration Days	Area Exposed ft²	Current Density ma/ft²	Electrode Negative Potential (Hydrogen = Zero) Start	Electrode Negative Potential (Hydrogen = Zero) End	Overall Cell Voltage V.T. V.M. Reading		Composition Cell Electrolyte	Composition Cell Electrolyte	pH Start	pH End	Cathode Appearance
6-55-1	Continuous Protection	28	0.17	100	1.126	1.267			Soil	50,000 ppm NaCl		6.2	No Corrosion
2	Continuous Protection	28	0.17	100	1.269	1.180			Soil	50,000 ppm $CaCl_2$	7.3	6.1	No Corrosion
3	Continuous Protection	28	0.17	100					Soil	50,000 ppm $MgCl_2$		7.1	No Corrosion
7-55-1	Continuous Protection	28	0.17	100			1.8	2.3	Soil	50,000 ppm NaCl	6.7	4.7	No Corrosion
2	Continuous Protection	28	0.17	100			1.75	2.25	Soil	50,000 ppm $CaCl_2$	6.1	7.3	No Corrosion
3	Continuous Protection	28	0.17	100			1.8	2.1	Soil	50,000 ppm $MgCl_2$	6.8	6.5	No Corrosion
8-55-1	Continuous Protection	28	0.01	500	1.306	1.398	2.45		Soil	12,500 ppm each of $CaCl_2$, $MgCl_2$, NaCl, KCl	6.5	6.8	No Corrosion
2	Continuous Protection	28	0.01	500	1.304	1.505	2.5		Soil	12,500 ppm each of $CaCl_2$, $MgCl_2$, NaCl, KCl	7.2	7.2	No Corrosion
3	Continuous Protection	28	0.01	500	1.326	1.314	2.25		Soil	12,500 ppm each of $CaCl_2$, $MgCl_2$, NaCl, KCl	5.7	4.4	No Corrosion
9-55-1	Continuous Protection	28	0.07	72					Soil	25,000 ppm each of KCl and $CaCl_2$	6.8	7.3	No Corrosion
2	Continuous Protection	28	0.07	72					Soil	25,000 ppm each of NaCl and $CaCl_2$	7.2	7.4	No Corrosion
3	Continuous Protection	28	0.07	72					Soil	12,500 ppm each of $CaCl_2$, $MgCl_2$, NaCl, KCl	4.4	6.1	No Corrosion
10-55-1	Continuous Protection	28	0.17	500	1.321	1.260	1.95		No Soil; electrolite only	15,000 ppm each of $CaCl_2$, NaCl, KCl	7.0	2.7	No Corrosion
2	Continuous Protection	28	0.17	1000	1.264	1.338	2.1		No Soil; electrolyte only	15,000 ppm each of $CaCl_2$, NaCl, KCl	6.6	2.6	No Corrosion
3	Continuous Protection	28	0.17	2000	1.358	1.591	2.2		No Soil; electrolyte only	15,000 ppm each of $CaCl_2$, NaCl, KCl	8.4	3.9	No Corrosion
11-55-1	Continuous Protection	28	0.17	500	1.202	1.129			No Soil; electrolyte only	15g/l KCl + 10g/l KOH	13.0	12.5	No Corrosion
2	Continuous Protection	28	0.17	1000	1.257	1.284			No Soil; electrolyte only	15g/l KCl + 10g/l KOH	13.0	12.3	No Corrosion
3	Continuous Protection	28	0.17	2000	1.346	1.300			No Soil; electrolyte only	15g/l KCl + 10g/l KOH	13.0	12.6	No Corrosion
12-55-1	Continuous Protection	28	0.17	2000	1.248	1.267			No Soil; electrolyte only	15g/l KCl + 10g/l KOH	13.0	12.9	No Corrosion
2	Continuous Protection	28	0.17	2000	1.307	1.480			No Soil; electrolyte only	15,000 ppm each of NaCl, KCl, $CaCl_2$	7.6	7.8	No Corrosion
13-55-1	Weekly Intermittent Protection	56	0.17	500	1.284	1.322			No Soil; electrolyte only	15,000 ppm each of $CaCl_2$, NaCl, KCl	4.6	5.9	Slight Pitting
2	Weekly Intermittent Protection	56	0.17	1000	1.327	1.186			No Soil; electrolyte only	15,000 ppm each of $CaCl_2$, NaCl, KCl	5.0	6.2	Slight Pitting
3	Weekly Intermittent Protection	56	0.17	2000	1.289	1.106			No Soil; electrolyte only	15,000 ppm each of $CaCl_2$, NaCl, KCl	4.7	5.4	Slight Pitting
14-55-1	Weekly Intermittent Protection	28	0.17	500	1.275	1.123			No Soil; electrolyte only	10g/l NaCl + 15g/l Na OH	12.4	12.4	Deep Pits
2	Weekly Intermittent Protection	28	0.17	1000	1.322	1.114			No Soil; electrolyte only	10g/l NaCl + 15g/l NaOH	12.4	12.4	Deep Pits
3	Weekly Intermittent Protection	28	0.17	2000	1.412	1.171			No Soil; electrolyte only	10g/l NaCl + 15g/l NaOH	12.4	12.4	No Corrosion
15-55-1	Daily Intermittent Protection	56	0.17	500	1.166	1.422			No Soil; electrolyte only	10g/l NaCl + 15g/l NaOH	12.4	12.4	Slight Pitting
2	Daily Intermittent Protection	56	0.17	1000	1.242	1.555			No Soil; electrolyte only	10g/l NaCl + 15g/l NaOH	12.4	12.4	Slight Pitting
3	Daily Intermittent Protection	56	0.17	2000	1.295	1.223			No Soil; electrolyte only	10g/l NaCl + 15g/l NaOH	12.4	12.4	Slight Pitting
16-55-1	Daily Intermittent Protection	56	0.50	50	1.216	1.228	1.9		Soil	50,000 ppm NaCl	6.5	5.7	No Corrosion except at air interface
2	Daily Intermittent Protection	56	0.50	50	1.235	2.9	2.1		Soil	50,000 ppm $CaCl_2$	6.8	5.7	No Corrosion except at air interface
3	Daily Intermittent Protection	56	0.50	50	1.246	2.35	2.35		Soil	50,000 ppm $MgCl_2$	6.5	5.6	No Corrosion except at air interface
17-55-1	Continuous Control on Series 16-55	56	0.50	50	1.229	4.4	4.4		Soil	50,000 ppm CaCl	6.1	5.8	No Corrosion
2	Continuous Control on Series 16-55	56	0.50	50	1.259	1.941	2.2		Soil	50,000 ppm $MgCl_2$	6.8	5.2	No Corrosion

Note No. 1—All cells except Series 12-55 had Graphite Anodes. Series 12-55 had Duriron Anodes.

Note No. 2—The pH values given in the table are those of a sample of cathodic protection cell electrolyte taken midway between the anode and cathode and are not representative of the catholyte at the lead cathode. The catholyte pH was invariably found to rise to a range of 10.5 to 12.5 pH irrespective of the cell pH.

Note No. 3—Because of the relatively small cathode area employed, the concentric spacing of anodes and cathode and the constant current circuit, it is believed to be a valid assumption that current density was uniform over the cathode area exposed. A concentric build-up of films or crusts on the cathodes is also considered as evidence of uniform current density. The current densities shown therefore are considered to be actual rather than computed values.

Note No. 4—The method of measuring cathode potentials is described earlier in the paper and Table 1 gives dynamic potentials with current to the cathode rather than static potentials. The potential measured will be a function of the current density, pH of the catholyte and the nature and thickness of cathode films or crusts. In the absence of measurements of resistive and capacitance components of the cathode film and of the pH of the catholyte, the potentials given in the table are to be considered as the result of the integrated effects of these various factors.

crust was formed on the lead cathodes during cathodic protection, whenever calcium or magnesium salts were present in high concentrations. The crust which formed when soil was used in the cell and was in contact with the cathode was greater in thickness than when the salt solution was used without soil.

Figure 3 illustrates the crust formation on cathodically protected lead cable sheath in soil saturated with sodium, calcium and magnesium chloride. Duration of run was 1½ months at the time photograph was made. In some cases the crust built up to a total thickness of one or more inches with the soil particles apparently cemented to each other and to the cathode. Crust formation also was intensified by increased current density and by increased calcium and/or magnesium content of the electrolyte in the cell.

For the continuous cathodic protection tests in which the cathode was not inspected until the end of the test period, it was possible to follow the build up of the cathode crust by means of potential or cell voltage values. The voltage of the cell built up more rapidly and to higher values for calcium than for magnesium crusts. For one test, at the end of one month, it required 175 volts to provide a 500 ma/square foot current density in a soil saturated with a concentrated $CaCl_2$ solution. The equivalent cathode in $MgCl_2$ solution required 65 volts for the same current density.

Initially when the lead cable sheath cathodes were removed from the cells they were carefully inspected by removing the cathode crusts on part of the surface and examining for absence of corrosion. The inspection consisted of visual observation of the cathode surface aided by magnification to 20 power and metallographic observation of polished and etched cross sections through the cathode surface. Later in the testing sequence the crusts were allowed to remain on some of the cathodes and were simply dry stored in the laboratory. It was then found that quite severe corrosion took place underneath the crusts formed in cells with high concentrations of either calcium or magnesium chlorides. The appearance of the corroded surface was an exact duplicate of the appearance of samples obtained from service failure due to so called cathodic corrosion. The corrosion was evidently initiated by crusted environment of the cable sheath after the cathode was removed from the cell.

Some of the crusts produced by continuous cathodic protection in cells containing high concentrations of Ca or Mg ions were partially removed from the lead cable cathodes. They were broken into small fragments and leached with a minimum of distilled water. The pH values of the leached solutions were found to range from about 10 to 11.5, thus indicating that in the presence of moisture and absence of cathodic protection current the crusts were highly alkaline and corrosive to the lead.

It was possible to observe from the data obtained (see Figure 3) that cells operating with soil saturated with a concentrated NaCl solution had a minimum of crust formation on the lead cathode. However, a photometric analysis of the crust which did form showed that it consisted mainly of hydrated oxides of Ca and Mg. The indications here are that an ion interchange had occurred between the Na and the available Ca and Mg of the soil itself. More quantitative data in this area would be a desirable aim for research activity.

Figure 3—Appearance of ⅞-inch OD lead cable sheath cathodes protected 1½ months in soil saturated with chloride solution (50,000 ppm concentration). From left to right the chloride added to the cell was sodium, calcium and magnesium. The polyvinyl tape used for insulation is shown at the top and bottom of the specimens.

Summary and Conclusions

Under very special laboratory conditions chemists have shown that deterioration of lead cathodes may take place. But in such cases the appearance of the cathode and the degree of environmental specialization rules out the type of lead deterioration which has been claimed with regard to lead covered cables operating under field conditions of cathodic protection.

The large number of tests which have been made of lead cable sheaths under a variety of conditions of cathodic protection in the CPL have demonstrated in every case that effective protection is maintained as long as protective current exists. The laboratory circuits used for supply of protective current to the cathodic protection cells had characteristics which would not be found in the usual cathodic protection system in the field. This was because they maintained constant current to the cathodes independently of any change in resistance due to crust or film formation.

It was found that crust formation on the lead cathode was a consequence of cathodic protection in the presence of calcium and magnesium salts. Crust formation was found to be greater when the concentration of these salts or the current density was increased. Crust formation also was found to be a maximum when soil was in contact with the lead cathode. Although crust formation was not serious on lead cathodes protected in solutions containing NaCl, there was some slight crust formation when in contact with soil saturated with NaCl solution. All of the crusts were found by photometric analysis to consist mainly of the hydrated oxides of calcium and magnesium, and they provided a highly alkaline and corrosive environment in the absence of protective current. This is believed to be the first recorded laboratory duplication of service-type failure under cathodic protection conditions.

It is considered that a system of lead-sheathed cable normally under cathodic protection may cease

to have such protection as a result of the following service-connected factors:

1. Formation of films and crusts of high resistance due to Ca and Mg oxide composition.
2. Seasonal removal of soil moisture or duct water.
3. Formation of a more highly conducting path of cathodic protection somewhere else in the system due to heavy concentration of de-icing salts.
4. Daily and seasonal variation of stray currents.

Since the corrosive environment of lead cable sheath may be produced by the cathodic protection system itself, it will be recognized that failure by corrosion in the absence of protective current will be more rapid the greater the protective current density prior to cessation of protection. It would, therefore, appear that the term "cathodic corrosion" of lead cable sheath is a misnomer and should be replaced in the literature by the more descriptive term "corrosion by cathodic products."

Some reduction in the frequency of failure of lead sheathed cable might be effected in the field by preventing the existence of excessive protective current. More precise inspection techniques could possibly determine when cathodic protection is absent as a consequence of the four factors mentioned. If any of these conditions are found by such inspection, the application of an appropriate system of mitigation can be attempted more effectively when the specific cause of non-protection has been established.

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Any discussion of this article not published above will appear in the June, 1957 issue.

70 Technical Committees to Meet at St. Louis

Tentative Committee and Technical Program

NACE 13th Annual Conference, St. Louis, March 11-15, 1957

Sunday, March 10—Sheraton-Jefferson Hotel

Morning

T-2E—Internal Corrosion of Product Pipe Lines and Tanks
T-3B—Corrosion Products
T-5A-4—Chlorine
T-6G—Surface Preparation for Organic Coatings

Afternoon

T-2D—Standardization of Procedures for Measuring Pipe Coating Leakage Conductance
T-4A—Effects of Electrical Grounding on Corrosion
T-5A-6—HF Corrosion
T-6B—Protective Coatings for Resistance to Atmospheric Corrosion

Monday, March 11—Sheraton-Jefferson Hotel

Morning

T-1—Corrosion in Oil and Gas Well Equipment
T-2A—Galvanic Anodes
T-2C—Minimum Current Requirements
T-2F—Internal Corrosion of Crude Oil Pipe Lines and Tanks
T-2G—Coal Tar Coatings for Underground Use
T-2J—Wrappers for Underground Pipe Line Coating.
T-4F-1—Materials Selection in the Water Industry
T-5A-1—Sulfuric Acid
T-5A-5—Nitric Acid
T-5E—Stress Corrosion Cracking of Austenitic Stainless Steel
T-6H—Glass Linings and Vitreous Enamels
T-4F-2—Materials Selection in the Electric Industry.

Afternoon

T-1—Corrosion in Oil and Gas Well Equipment
T-2B—Anodes for Impressed Currents
T-3C—Annual Losses Due to Corrosion
T-4D—Corrosion by Deicing Salts
T-4F—Materials Selection for Corrosion Mitigation in the Utility Industry
T-5A-3—Acetic Acid
T-5B-3—Oil Ash Corrosion
T-5D—Plastic Materials of Construction
T-6D—Industrial Maintenance Painting
T-6K—Corrosion Resistant Construction with Masonry and Allied Materials
T-5A—Chemical Manufacturing Industry
T-5B-5—Corrosion by Molten Salts and Metals

Tuesday, March 12—Kiel Auditorium

Morning

T-2H—Asphalt Type Pipe Coating
T-3D-1—Electrical Holiday Inspection of Coatings
T-4B-6—Stray Current Electrolysis
T-5B-2—Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry
T-6F—Protective Coatings Equipment, Methods and Cost
T-4B-1—Lead and Other Metallic Sheaths
T-3D—Instruments for Measuring Corrosion
T-4B-2—Cathodic Protection
Chemical Industry Symposium—Part I
Oil and Gas Production Symposium

Afternoon

T-1D—Sour Oil Well Corrosion
T-1H—Oil String Casing Corrosion
T-3A—Corrosion Inhibitors
T-3G—Cathodic Protection
T-4B-3—Tests and Surveys
T-4B-4—Protection of Pipe Type Cables
T-4B-5—Non-Metallic Sheaths and Coatings
Protective Coatings Symposium
Refinery Industry Symposium
Educational Lecture No. 1
Pipe Line Group Discussions

Wednesday, March 13—Kiel Auditorium

Morning

T-1B—Condensate Well Corrosion
T-2K—Prefabricated Plastic Film for Pipe Line Coating
T-3H—Tanker Corrosion
T-5B—High Temperature Corrosion
T-6A—Organic Coatings and Linings for Resistance to Chemical Corrosion
T-6C—Protective Coatings Resistance to Marine Corrosion
T-7—Corrosion Coordinating Committee
Corrosion Principles Symposium
Corrosion Inhibitors Symposium
General Business Meeting

Afternoon

T-1K—Inhibitors for Oil and Gas Wells
T-2—Pipe Line Corrosion
T-6R—Protective Coatings Research
T-1C—Sweet Oil Well Corrosion
General Corrosion Symposium
Educational Lecture No. 2
Chemical Industry Symposium—Part II
Cathodic Protective Symposium

Thursday, March 14—Kiel Auditorium

Morning

T-1M—Corrosion of Oil and Gas Well Producing Equipment in Offshore Installations
T-3E—Railroads
T-3F—Corrosion by High Purity Water
T-4—Utilities
T-6—Protective Coatings
Pipe Line General Symposium
Plastic Symposium
Elevated Temperatures

Afternoon

T-1F—Metallurgy
T-1J—Oil Field Structural Plastics
T-3E—Railroads
T-5—Corrosion Problems in the Process Industries
T-5B-2—Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry
T-6E—Protective Coatings in Petroleum Production
T-1G—Sulfide Stress Corrosion Cracking
High Purity Water Symposium
Educational Lecture No. 3
Power & Communication Industry Symposium
Corrosion Symposium
General Corrosion Symposium

Friday, March 15—Kiel Auditorium

Morning

General Corrosion Problems—Round Table
Pipeline and Underground Corrosion Problems—Round Table

Problems of Most Major Industries Will Be Covered

Seventy NACE technical committees will meet in St. Louis during the Thirteenth Annual Conference and Exhibition, March 11-15. There also will be meetings of the Corrosion Committee of the Federation of Paint & Varnish Production Clubs and a committee of the Society of Plastic Industry held concurrently with the conference.

A tentative schedule for the technical committee meetings appears elsewhere in this section of CORROSION. The schedule shows eight committees holding meetings on Sunday, March 10. These Sunday meetings were scheduled in an attempt to relieve the heavy schedule of committee meetings and symposia later in the week. They are open meetings to which guests are invited to attend.

An outline of tentative plans for each committee meeting follows:

T-1 Corrosion in Oil and Gas Well Equipment—All day Monday, March 11. T-1 will hear progress reports from each of the ten T-1 unit committees. A portion of the day's meeting will be devoted to round table discussion of new developments and procedures concerning corrosion mitigation in the oil and gas production industry.

T-1A Corrosion in Oil and Gas Well Equipment, Los Angeles Area—T-1A will not hold a meeting but will report on its 1956 activities at the T-1 meeting on Monday.

T-1B Condensate Well Corrosion—Wednesday am, March 13. Progress made by a task group on completion of wells with shut in surface pressures near 10,000 psi will be discussed. The task group is assembling and correlating information concerned with completion practices, production practices, materials used and corrosion control measures connected with the 10,000 psi wells. Other subjects to be discussed will include new developments in inhibitors for use in condensate wells, developments in methods of applying inhibitors and special equipment for introducing inhibitors into wells with shut in pressures near 10,000 psi.

T-1C Sweet Oil Well Corrosion—Wednesday pm, March 13. Results of a questionnaire on tubing internally coated with plastic coatings will be discussed. Task groups on field and laboratory aspects of corrosion of both water-dependent and water-independent sweet-oil wells will present progress reports.

T-1D Sour Oil Well Corrosion—Tuesday pm, March 12. T-1D will discuss progress of task groups active in the West Texas-New Mexico and Western Kansas areas. The committee will continue discussion of developments concerning corrosion in sour oil wells in connection with their assignment to keep T-1 advised of latest mitigation measures.

T-1F Metallurgy—Thursday pm, March 14. T-1F will discuss problems of a metallurgical nature in the petroleum production industry.

T-1G Stress Corrosion Cracking—Thursday pm, March 14 (immediately following the T-1F meeting). T-1G will discuss a proposed standard method for determining susceptibility of steels to cracking under stress when exposed to hydrogen sulfide. New committee activities will be discussed.

T-1H Oil String Casing Corrosion—Tuesday pm, March 12. T-1H will hear of progress by task groups in West Texas-New Mexico, West Kansas, East Texas and California areas. Discussion

(Continued on Page 80)

Sweet Oil Well Iron Content Anomaly to Be Investigated

Field tests are being planned to confirm laboratory findings of an anomalous condition with respect to iron content of effluent from sweet oil wells. A member of T-1C on Sweet Oil Well Corrosion has reported that his experiments with well fluids in the laboratory show that the addition of an inhibitor changes the ratio of iron content in the water and oil phases.

When inhibitor is added iron content of the water decreases while the iron content of the oil increases, while the total amount of iron remains fairly constant.

Bottom Hole pH Scanned As Indicator of Corrosivity

Will bottom hole pH indicate whether or not a well will become corrosive? This is the aim of a task group of T-1C on Sweet Oil Well Corrosion which is seeking to determine if the calculated bottom hole pH can be used as a criterion of corrosivity early in the life of an oil well.

70 Technical–

(Continued From Page 79)

of data accumulated on cathodic protection of oil well casings will be heard.

T-1J Oil Field Structural Plastics—Thursday pm, March 14. T-1J will discuss results of a questionnaire on use of plastic pipe in the petroleum production industry. Performance data will be discussed.

T-1K Inhibitors for Oil and Gas Wells—Wednesday pm, March 13. T-1K will discuss progress made on a proposed test for inhibitors to be used in sour crudes and a test for inhibitors to be used in sweet crude and/or gas condensates. Further laboratory tests by the T-1K screening method will be discussed.

T-1M Corrosion of Oil and Gas Well Producing Equipment in Offshore Installations—Thursday am, March 14. Will discuss progress by task groups on coatings, surface preparation and costs.

T-2A Galvanic Anodes—Monday am, March 11. T-2A will hold a round table type meeting with discussions from members on performance of various types of galvanic anodes.

T-2B Anodes for Impressed Currents—Monday pm, March 11. T-2B will hear a report on the results of the second questionnaire on high silicon cast iron anodes. Progress of task groups on sources of impressed current for anodes, ground bed design and use of platinum and palladium for anodes will be discussed.

T-2C Minimum Current Requirements—Monday am, March 11. A statement on "Minimum Requirements for Cathodic Protection" has been proposed. The committee will discuss the statement and measurement techniques to be used to establish the criteria.

T-2D Standardization of Procedures for Measuring Pipe Coating Leakage Conductance—Sunday pm, March 10. T-2D will discuss the committee's proposed standard method for measuring leakage conductance of coating on buried pipelines. Reports on measuring leakage conductance under special conditions will be heard from task groups of the committee.

T-2E Internal Corrosion for Product Pipeline Tanks—Sunday am, March 10. It is expected that preliminary reports on the committee's in-line coupon tests will be heard at the meeting. There will be a general discussion of the committee's test program.

T-2F Internal Corrosion of Crude Oil Pipeline and Tanks—Monday am, March 11. Plan for reorganizing the activities and reactivating old activities of the committee will be discussed.

T-2J Wrappers for Underground Pipeline Coating—Monday am, March 11. Completed material specifications for asbestos felt and glass fibers will be discussed at the meeting. Preliminary specifications on other type wrappers will be discussed.

T-2K Prefabricated Plastic Film for Pipeline Coating—Wednesday am, March 13. Progress of task groups on history and results of physical characteristics research development, application and standards will be discussed. Results of questionnaires on field installations on present and long range data and on laboratory data for industry and manufacturers is anticipated. Possible recommendations regarding prefabricated plastic films for pipeline coatings will be considered.

T-3A Corrosion Inhibitors—Tuesday pm, March 12. Reports of progress from task groups on general theory of the application of the corrosion inhibitors, methods of testing and screening corrosion inhibitors and materials available for application of corrosion inhibitors will be heard and discussed.

T-3B Corrosion Products—Sunday am, March 10. The committee's series of bibliographies of corrosion products on metal will be the main topic of discussion at the meeting.

T-3C Annual Losses Due to Corrosion—Monday pm, March 11. Progress made by the committee on ascertaining losses due to corrosion will be discussed.

T-3D Instruments for Measuring Corrosion—Tuesday am, March 12. Committee will discuss instruments and techniques for measuring corrosion. Task group on electrical holiday correction of coating will hold a meeting immediately following the T-3D meeting.

T-3E Railroads—Thursday am, March 14. T-3E will hold a general round table discussion type meeting on problems of corrosion in the railroad industry.

T-3E-1 Corrosion of Railroad Tank Cars will meet on Thursday afternoon. The major topic for discussion at the meeting will be the development of a preliminary chart on the cleaning of tank cars to prevent damage to linings or construction materials.

T-3F Corrosion by High Purity Water—Tuesday pm, March 13. T-3F will hear discussions of progress made by task groups on facilities for the production of high purity water, inhibitors, corrosion products, general corrosion problems, classification and bibliographies. The third annual symposium sponsored by the committee will be held Thursday pm, March 13.

T-3G Cathodic Protection—Tuesday pm, March 12. T-3G will hear discussions of progress by task groups on cathodic protection of hull bottoms of ships, heat exchangers and process equipment. Task Group T-3G-1 on Cathodic Protection of Hull Bottoms of Ships will present a revised report. Task Group T-3G-2 on Cathodic Protection of Heat Exchangers expects to have available for discussion results of a questionnaire.

T-3H Tanker Corrosion—Tuesday am, March 12. Developments for protecting tankers from corrosion will be discussed.

T-4A Effects of Electrical Grounding on Corrosion—Sunday pm, March 10. T-4A will hear discussions of activity on the part of task groups on recommendations for materials to be used for electrical grounding to reduce corrosion and recommendations for grounding on private premises.

T-4B Corrosion of Cable Sheaths—All day Tuesday, March 12. The T-4B meeting will consist of progress reports by the six T-4B task groups. The task groups will report in the following sequence: T-4B-6 on Stray Current Electrolsis; T-4B-1 Lead and other Metallic Sheaths; T-4B-2 Cathodic Protection; T-4B-3 Test and Surveys; T-4B-4 Protection of Pipe Type Cable; T-4B-5 Non-Metallic Sheaths and Coatings.

T-4D Corrosion by Deicing Salt—Monday pm, March 11. T-4D will hear discussions of progress from task groups assigned to study and develop procedures for conducting field tests above ground, study and develop procedures for conducting field tests between cities and transportation companies and a task group assigned to study and develop procedures for conducting field tests below ground.

T-4E Corrosion by Domestic Waters—Tuesday pm, March 12. The committee will discuss progress on its service tests in domestic waters. Data on exposed pipe test sections and on aluminum

(Continued on Page 81)

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Inhibitor Screening Method Satisfactory In Extensive Use

No inhibitor which failed the NACE Unit Committee T-1K Proposed Standard Laboratory Procedure for Screening Inhibitors for use in Oil and Gas Wells has functioned satisfactorily in the field so far. The screening procedure, published in CORROSION, Vol. 11, No. 3, 143t-146t (1955) March, has been used by many oil production laboratories for screening inhibitors for nearly two years. The testing laboratories have furnished the committee with data on inhibitor screening which substantiates effectiveness of the procedure.

Essentially the static oil and water test utilizes the weight loss difference of mild steel coupons under the influences of inhibited and uninhibited solutions of synthetic sour brine. The test subjects the steel coupon to an inhibited solution of oil, in the case of oil-soluble inhibitors, for a short period and for

(Continued on Page 82)

70 Technical—

(Continued From Page 80)

pipe exposed to irrigation waters will be heard. Discussion on forming a task group to study corrosion of hot water tanks will be held.

T-4F Materials Selection for Corrosion Mitigation in the Utility Industry—Monday pm, March 11. T-4F will hear reports on progress by task groups on material selection in the water industry and material selection in the electrical industry. These task groups will meet on Monday am, March 11.

T-5A Chemical Manufacturing Industry—Monday pm, March 11. T-5A will hear discussions of progress from task groups on sulfuric acids, acetic acid, chlorine, nitric acid and hydrofluoric acid. Task groups will hold meetings as follows: T-5A-1 Sulfuric Acid, Monday am, March 11; T-5A-4 Chlorine, Sunday pm, March 11; T-5A-5 Nitric Acid. Monday am, March 11; T-5A-6 Hydrofluoric Corrosion, Sunday pm, March 10.

T-5B High Temperature Corrosion—Wednesday am, March 13. T-5B will discuss progress by task groups on sulfide corrosion at high temperatures and pressures in the petroleum industry, oil ash corrosion and corrosion by molten salt and metals. The task groups will hold their meetings as follows: T-5B-2 Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry, Tuesday am, March 12 and Friday pm, March 14; T-5B-3 Oil Ash Corrosion, Monday pm, March 11; T-5B-6 Corrosion by Molten Salt and Metal, Monday pm, March 11.

T-5D Plastic Materials of Construction—Monday pm, March 11. T-5D will hear reports on progress made by task groups on questionnaires, organic, alkalis, gases, water and salt solutions, organic chemicals, engineering design and methods for evaluating plastics in chemical environments. A major item for discussion at the T-5D meeting will be the task group T-5D-7 on Engineering Design of the proposed T-5D Plastic Materials of Construction Numbering System.

T-5E Stress Corrosion Cracking Stainless Steels Monday am, March 11. T-5E will discuss results of the joint ASTM Committee A-10 Sub. IV and T-5E questionnaire on Stress Corrosion Cracking of Stainless Steels.

T-6A Organic Coatings and Linings for Resistance to Chemical Corrosion—Wednesday am, March 13. T-6A will discuss progress by committees on heavy linings, vinyl coatings, vinylidene chloride polymers, phenolics, polyethylene, rubber and elastomors, silicones, methyacrylates, furnaces, polyesters, fluorocarbons, chlorinated rubbers, organic-brick covered, rigid vinyls, bituminous, polyurethanes and Hypalon.

T-6B Protective Coatings for Resistance to Atmospheric Corrosion—Sunday pm, March 10. T-6B will continue to work on a detailed study of coatings for use in atmospheric environments. Final draft for T-6B is report on protective coatings for atmospheric use, surface preparation and application requirements, physical characteristics and resistance (including a table of application data for paints and coatings used in atmosphere) will be discussed.

T-6C Protective Coatings for Resistance to Marine Corrosion—Wednesday am, March 13. T-6C will discuss completed charts giving data on coatings for use in a marine atmosphere. A discussion on expanding committee activities and scope will be held.

T-6D Industrial Maintenance Painting—Monday pm, March 11. T-6D, organized in October 1956, will discuss progress by task groups on economics, specifications and painting programs.

T-6E Protective Coatings in Petroleum Production—Thursday pm, March 14. T-6E will discuss results of questionnaires designed to determine present practices and to yield data that may supplement a contemplated recommended practices and suggested specifications for protective coatings used in petroleum production.

T-6F Protective Coatings, Equipment, Methods and Cost—Tuesday am, March 12. T-6F will discuss the committee's scope and complete organization of committee's activities.

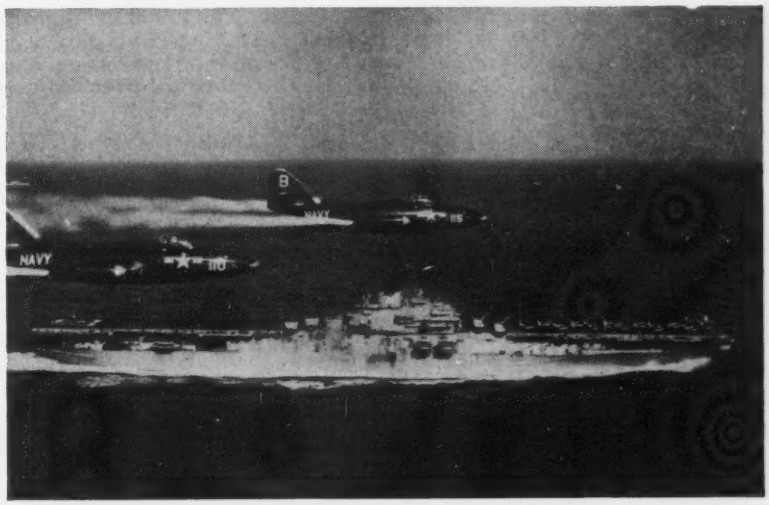
T-6G Surface Preparation for Organic Coatings—Sunday am, March 10. T-6G will discuss plans for preparation of specifications for surface preparation of various non-ferrous metals for coating.

T-6H Glass Linings and Vitreous Enamels—Monday am, March 11. T-6H will discuss plans for expanding committee activities.

T-6K Corrosion Resistant Construction with Masonry and Allied Materials—Monday pm, March 11. T-6K has just completed a comprehensive report on chemical resistant linings for the process industry. The committee will discuss new projects and future committee work.

T-6R Protective Coatings Research—Wednesday pm, March 13. T-6R will hear reports from liaison members to various coating committees of other organizations and discuss new areas of work for T-6 unit committees.

T-7 Corrosion Coordinating Committee—Wednesday am, March 13. T-7 will discuss progress made during the year on organization of regional corrosion coordinating committees. A major topic of discussion at the committee's meeting is the proposed revision of the Report of Correlating Committee on Cathodic Protection which was published by NACE in 1951.



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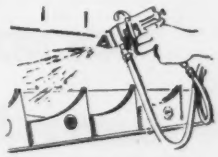

These illustrations are examples of the ability of Chromium Chemicals to inhibit and prevent corrosion. Besides supplying many industries with superior quality chromium chemicals, Mutual offers information on the numerous other ways that these chemicals help to protect valuable materials and equipment. So, if you are in doubt about the best way to solve your corrosion problem, contact Mutual.

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Roach Heads Canadian T-7 Coordinating Unit

Coated Tubing Experience Is Reported to T-1C

Several reports on experience with coated tubing have been received by Unit Committee T-1C on Sweet-Oil Well Corrosion. One member reported having 145 strings of coated tubing in one field and failure of only one string. The failure was discovered when wireline work was being done on the well. Close examination showed small bubbles in the coating over the entire tubing string with rust underneath the bubbles. In the opinion of the committee, the failure resulted from poor surface preparation, although some thought the bubbles may have been the result of not completely removing solvents.

Coated tubing has been in service in the field for five years. Design life of the coated tubing is on a seven-year basis although it is believed a four and one-half year life would still prove economical.

Another company reported on 96 sweet-oil wells in the Texas-Louisiana Gulf Coast area with coated strings. The oldest string, ten years old, was pulled recently for inspection and returned to service intact. This company has had three failures, each of different types of coating, all attributed to faulty application.

One member of the committee has made tests to see how plastic coated nipples hold up when parrafin is scraped off. Nipples with five different coatings were placed one on top of the other. A biscuit circular wire type paraffin cutter was forced through. The number of passes to failure varied from 18 for one coating to four for another.

Another member reported his company has set up a method of tests based on the assumption that velocity will damage coatings. Various sizes of coated samples were put in a pipe. In one test the diameter of the sample was such that the velocity was equivalent to that in a tubing string that produced 500 barrels of fluid a day. Diameter of the samples was varied to produce velocities equivalent to 1500 and 2500 barrels per day. Coatings have been watched over a period of several months. Some were eliminated very quickly and among others the baked phenolic and modified epoxy phenolic coatings stood up best. Air-dried coatings failed faster than baked.

Inhibitor Screening—

(Continued From Page 81)

the remainder of the test time the coupon is immersed in brine. In the case of the water-soluble inhibitor the brine is inhibited. Equipment for the test is so simple it is unique in a modern laboratory. It consists of a narrow mouth Erlenmeyer flask, a rubber stopper, a small glass hook and a 1 by 1 by 1/16-inch mild cold rolled sheared piece of steel. Preparation for the test also is relatively simple.

All tests are run in duplicate and duplicate controls are run at the time of all tests. Results of the tests are reported as: a) percent inhibition (in which the percentage of protection is calculated by a simple formula) and b) appearance of coupon (in which the surface of the coupon is examined visually using 25 to 100 power magnification and the resuts of the visual examination reported by a description of the surface relative to presence or absence and relative severity of pits and/or blisters). It is estimated by most people that have run the test that, after the initial equipment is set up, it takes only 13½ minutes to prepare each test, evaluate and record the results.

Rapid Progress Made In Setting Up New Unit Organizations

Unit Committee T-7F Canadian Region Corrosion Coordinating Committee is the first all-Canadian technical committee activity to be formed within the NACE technical committee organization. The committee was authorized by the original Technical Practices Committee approval for formation of Group Committee T-7 and six unit regional T-7 committees.

Chairman of Unit Committee T-7F is C. L. Roach of the Bell Telephone Company of Canada, Montreal. Mr. Roach was born in Nova Scotia and received a B.Sc. in Electrical Engineering from Nova Scotia Technical College. He received a Master of Engineering from McGill University He served as Major in the Canadian Ordnance Corps during the 2nd World War and has been affiliated with telephone engineering since 1923 and with the Bell Telephone Company of Canada since 1926. Presently he is Staff Engineer, Protection and Foreign Wire Relations. In addition to NACE he holds memberships in AIEE, IRE and Corporation of Professional Engineers of Quebec. He is chairman of the Canadian Standards Association Committee on Corrosion of Underground Structures.

Roach

Mr. Roach reports his committee is engaged at the moment in accumulating information as to existing electrolysis committees in Canada. Future activities of the committee will be in line with the scope of T-7.

Since T-7 was authorized in March 1956 Chairman J. M. Fouts, New York Telephone Co., Buffalo, N. Y. and Vice-Chairman C. A. Erickson, the Peoples Natural Gas Co., Pittsburgh, Pa. have been busy organizing activities at the regional level. Mr. Erickson is chairman of the Northeast Region Committee T-7A in addition to being vice-chairman of the group committee. Mr. Erickson has prepared attractive brochures for distribution to existing electrolysis and coordinating committees existing in the region inviting them to participate in T-7A activities.

J. O. Mandley, Michigan Consolidated Gas Co., Detroit has accepted the vice-chairmanship of the North Central Region Committee T-7B and is endeavoring to initiate activities in that region.

E. W. Seay, Jr., Chesapeake & Potomac Telephone Co. of Va., Norfolk, chairman of the Southeast Region Committee T-7C has been evaluating electrolysis committee activities in the region and inviting existing committees to participate in T-7 work.

O. W. Wade, Transcontinental Gas

(Continued on Page 85)

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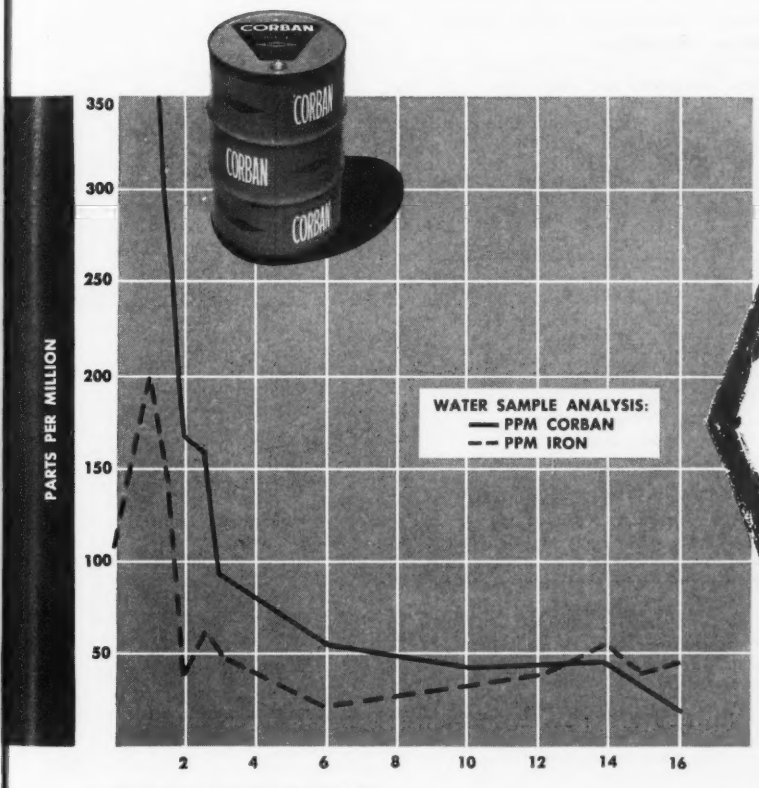
To date this new approach to the use of Corban for corrosion control has been even more successful than anticipated.



Case History of new Squeeze Technique with Corban

Production from this particular gas condensate well is about 10 MMCF per day, with about 150 bbls. of distillate and about one barrel of water. The squeeze treatment with Corban was performed by pumping 50 gallons of Corban 101, mixed with 30 gallons of fresh water, into the formation. This mixture was displaced with condensate and then over-flushed with 12 bbls. of condensate.

All of the pumping was done at a rate of about one barrel per minute. The maximum surface pressure was 5000 psi as the Corban was entering the formation. The pressure while the condensate was pumped into the formation was 4000 psi. No adverse effects on production were noted following the treatment. Corrosion protection was provided for 16 weeks—without having to open up the well for subsequent inhibitor treatments during this period.

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Magnesium Cased Inhibitors Give Good Results in Salt Water Producing Wells

It has been reported to Unit Committee T-1B on Condensate Well Corrosion that magnesium cased inhibitor sticks used in salt water producing wells give about the same results as conventional chemical treatment.

During a discussion concerning optimum percentage of active material in concentrated inhibitors it developed that some think materials with a low active content will perform as well as those more concentrated.

The committee is of the opinion that lubricators and pumps suitable for introducing inhibitors into wells with shut-in pressures in the neighborhood of 10,000 psi are available, but that lubricators for christmas trees of parallel string dual completions are not readily available. Some members reported successful well completions using macaroni tubing for introduction of liquid inhibitors into the well bore. The committee plans to assign a task group to assemble and correlate information on completion and production practices, material used, corrosion control measures and any other information considered useful to an operator faced with completing wells with shut in pressures near 10,000 psi.

Several members of T-1B have expressed concern over corrosion-abrasion of the lower tubing string opposite the upper perforations of parallel string dual completions. The usual practice has been to coat this section with lead or an epoxy material. One member reported inspecting epoxy coated material after nine months' service and finding it in good condition.

Improved Methods Urged For Using Inhibitors

Improved methods of using the many effective commercial inhibitors now available should be emphasized now, members of Unit Committee T-1C on Sweet Oil Well Corrosion believe. This does not diminish the importance of the film persistence factor, which predominantly determines success or failure or reduce the need for further investigation of persistence in sweet oil wells, the committee thinks.

Pumping inhibitors into the producing formation has received considerable attention recently. At least one company using the method feels it works well in wells producing less than 500 barrels of water a day, but when water volume exceeds 1000 barrels a day, it is not very advantageous because of the need to apply treatment frequently.

Iron content is the main criterion in determining when wells should be retreated, but equipment failure is used in evaluation. Life of tubing has doubled in some cases, but the best indication of success is the reduction in the number of tubing joints that must be replaced.

Good Results Reported

Another company has reported using this method in a well making 1000 barrels per day. The well was "squeezed" with one drum of weighted inhibitor

(Continued on Page 85)

Corrosion in Pipe Line Oil Wells With Static Water Levels Reported to T-1C

Corrosion has been found in pipe line oil producing wells which have a static water level. A member of T-1C on Sweet Oil Well Corrosion used bottom hole pressure surveys to determine corrosion while caliper surveys run in a few wells in one field showed corrosion was not confined to the portion containing water. Salinity of the water was not determined.

Several other members of the committee reported static water in some of their pipe line oil wells. One showed correlation to corrosion, and this member found corrosion at depths where water could be coalescing in the oil and falling back.

Improved Methods–

(Continued From Page 84)

followed with 160 barrels of water. After 40 days the iron remained fairly constant at 6 ppm compared with 31 ppm for the untreated well.

One member reports using magnesium sticks as weights to get inhibitors to well bottoms. When a low volume well producing 15-20 barrels of water and about the same amount of oil was treated with two sticks twice a week, a 75 percent reduction in iron content was obtained. The treatment was considered successful but was discontinued because pieces of magnesium were coming back up the tubing and clogging the chokes. It was concluded that a limiting factor to the use of magnesium weighted sticks may be the produced water volume needed to dissolve the magnesium.

The liquid type dump bailer method of treating has been used extensively in some areas as was reported in the December issue of CORROSION on page 100.

Chemical Pump Is Successful

One member reported use of a truck-mounted chemical pump for slug treatment at an average cost of 3 cents per barrel of oil. When used in a field with 50 pumping wells a reduction in well pulling of 54 percent was obtained, better than had been accomplished by any other method.

Roach Heads–

(Continued From Page 82)

Pipe Line Corporation, Houston, chairman of the South Central Region Committee T-7D has already added an area committee to his unit activities. This is the T-7D-1 Houston Section Corrosion Coordinating Committee which has been in existence since October 1955.

Irwin C. Dietze, Department of Water & Power, Los Angeles, California, chairman of the Western Region Committee T-7E is assessing coordinating committee activities in his region.

Mr. Fouts and Mr. Erickson are shown on the cover of this issue of CORROSION studying the Report of The Correlating Committee on Cathodic Protection published in 1951. Plans are underway to revise the report so it can be included in T-7 recommendations at the committees meeting to be held in St. Louis March 13, first meeting of the group committee.

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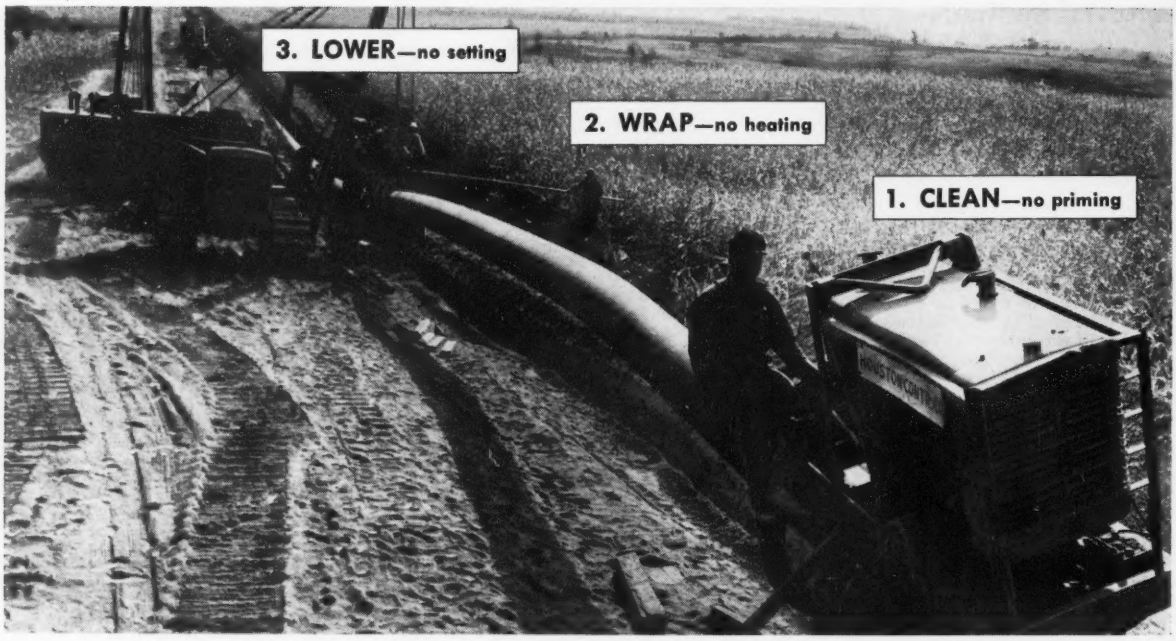

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NACE NEWS

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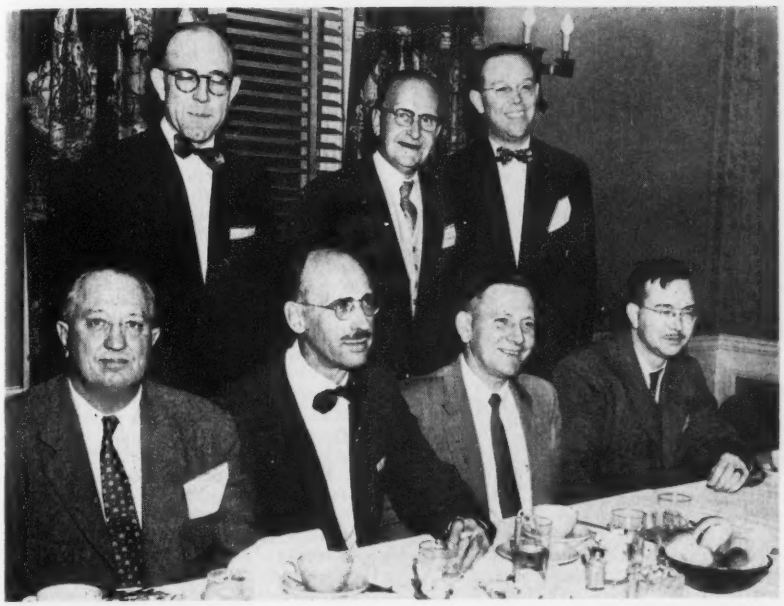

BALTIMORE SECTION heard Kenneth Tator, Tator Associates (seated, second from left), talk on Organic Coatings for Corrosion Protection at its November 27 meeting attended by 34 members and guests. Others in the photograph are, standing, left to right: A. C. Burton, Armco Steel Corp., 1957 secretary-treasurer; W. J. Mayer, A. N. Byers Co., 1957 chairman; George E. Best, Mutual Chemical Division, Allied Chemical and Dye Corp., regional director; seated, left to right, J. H. Parran, 1956 vice-chairman; Mr. Tator; B. J. Philibert, Olin Mathieson Chemical Corp., 1956 chairman and Curtis H. Elliott, Jr., Davison Chemical Co., Div. of W. R. Grace Co., 1957 vice-chairman.

Technical Program And Committee Sessions Planned

A two and one-half day technical meeting has been scheduled by Northeast Region for October 5-8, 1958 at the Somerset Hotel, Boston. This meeting may be the first under a proposed new program for the region whereby only one meeting will be held each year, and that in the fall. The Greater Boston Section, which will have responsibility for the 1958 meeting has recommended to Northeast Region officers that the existing policy of holding spring and fall meetings be changed.

Plans proposed for the 1958 session at a December 13 meeting of Greater Boston Section's governing board include:

Sunday, October 5—Administrative board meetings.

Monday, October 6—Registration. Morning and afternoon technical sessions; technical committee meetings.

Tuesday, October 7—Registration. Morning and afternoon technical sessions; technical committee meetings. Evening dinner.

Wednesday, October 8—Morning technical sessions.

No ladies' program is contemplated.

Monday and Tuesday sessions are to include topics of widest interest and the more specialized topics are to be given Wednesday.

Chairmen of technical committees are urged to consider meetings of their committees during the conference, with the assurance that efforts will be made to set them at times when no closely related subject matter is under discussion.

The section governing board has recommended that the region adopt a policy of holding a meeting annually between the dates of September 15 and November 30, beginning with 1958.

Present for the discussion were; Edward C. Rue, Boston Edison Co.; J. Dwight Bird, The Dampney Co.; Manson Glover, Glover Coating Co., Inc. and Mssrs. Jacobson and Miller.

Louisville ASM, Ohio Valley Section NACE Plan 5-Paper Symposium at Louisville Mar. 1

A one-day, five-paper corrosion symposium sponsored jointly by Louisville Chapter American Society for Metals and Ohio Valley Section NACE will be held March 1 at General Electric Company's Appliance Park in Louisville, Ky.

The program will be as follows:

Morning Session

Fundamentals of Corrosion, Norman Hackerman, University of Texas, Austin.

Corrosion of Stainless Steel, George Paul, The International Nickel Co., Inc.

Afternoon Session

Corrosion of Copper and Copper-Base Materials, A. W. Tracy, American Brass Co.

Corrosion of Aluminum, M. J. Pryor, Kaiser Aluminum & Chemical Corp.

Evening Session

Protective Measures, W. W. Bradley, Bell Telephone Laboratories.

Registration can be made with or information obtained from D. C. Brown, Tube Turns, Inc., 2820 West Broadway, Louisville, Ky.

Eastern Wisconsin Section

D. H. Westermann, Miller Brewing Co., was elected 1957 chairman of Eastern Wisconsin Section along with E. A. Witort, Steel Sales Co., vice-chairman and Harold F. Haase, consultant, secretary-treasurer, all of Milwaukee

Over 200 Attend Detroit Regional Meeting Nov. 15-16

More than 200 persons attended the NACE North Central Region First Annual Meeting at Detroit November 15-16. Symposia were presented on the construction industry, industrial power, chemical industry and automotive industry. A number of registrants visited Chrysler Corporation's Wyandotte Chemicals plant or the mine of the International Salt Company.

W. H. Stewart, Sun Pipe Line Co., Beaumont, Texas spoke on "NACE Aims and Value to Members" at the Thursday night banquet.

NOTICE ON PAYMENT OF 1957 NACE DUES

Invoices for 1957 membership dues have been sent to all Acitve and Junior NACE members. These dues are payable January 1, 1957. The NACE by-laws state that no member with dues in arrears for three months shall receive the publications of the association until such dues are paid.

• Accordingly the names of Active and Junior members whose 1957 dues have not been received by March 30, 1957 will be removed from the mailing list to receive CORROSION. No mailings of CORROSION will be made to delinquent members until dues are paid.

PERMIAN BASIN SECTION'S 1957 officers, installed at the section's December 10 meeting are, left to right: Marion Ziober, Atlantic Refining Co., Midland, secretary-treasurer; Jack Collins, Continental Oil Co., Midland, first vice-chairman; Roscoe Jarmon, Cardinal Chemical Co., Odessa, second vice-chairman; H. W. (Jack) Gray, Sivalls Tanks, Inc., Odessa, chairman. John C. Watts, internal Pipeline Maintenance, Odessa showed a color motion picture film "How Successful Are Internal Pipeline Coatings and Why."

Oklahoma City Symposia Chairmen Are Named

F. A. Prange Is Elected Tulsa Section Chairman

The following officers have been elected to serve the Tulsa Section for 1957: Frederick A. Prange, Phillips Petroleum Company, chairman; O. W. Everett, Oklahoma Natural Gas Company, vice-chairman; Parke D. Muir, Dowell, Inc., secretary and Roger J. Norris, Koppers Company, Inc., treasurer.

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Chairmen of six symposia to be given during the October 1-4 South Central Region meeting at Oklahoma City have been named. Dan H. Carpenter, Aquaness Dept., Atlas Powder Co., general arrangements chairman also reported that the air-conditioned municipal auditorium will be used for both meeting rooms and the region's second exhibition.

Technical program chairmen W. C. Koger, Cities Service Oil Co., and L. A. Hugo, Phillips Petroleum Co., both of Bartlesville, Okla. announced the following symposia would be held and named the chairmen responsible:

Gas Distribution—O. W. Everett, Oklahoma Natural Gas Co., Tulsa.

Oil and Gas Production—Jack L. Battle, Humble Oil & Ref. Co., Houston.

Marine Corrosion—R. M. Robinson, Continental Oil Co., New Orleans.

Cathodic Protection—Y. W. Titterington, Corrosion Service, Inc., Tulsa.

Protective Coatings—L. G. Sharpe, Napko Corp., Odessa.

Process Plants—W. G. Ashbaugh, Carbide & Carbon Chemicals, Texas City.

Two NACE Short Courses Are Scheduled During 1957

Two short courses on corrosion control have been scheduled by NACE sections as follows:

Tulsa Section—Eighth Annual Tulsa Corrosion Short Course, Mayo Hotel, Tulsa, February 13-15.

University of Oklahoma-Central Oklahoma Section—University of Oklahoma, Norman, April 2-4.

Teche Section is considering a short course later during the year.

Also scheduled for 1957 are the following short courses:

Appalachian Underground Corrosion Course—West Virginia University, Morgantown, June 4-6.

University of Illinois Short Course on Corrosoion, University of Illinois, Urbana, December 9-13.

•

The 10-Year Index to CORROSION now available has more than 4000 reference phrases.

NACE MEETINGS CALENDAR

Feb.

4 North Texas Section, Dallas. Use of Glass Coatings in Combating Corrosion, Forrest W. Nelson, A. O. Smith Corp.

5 Philadelphia Section. Kel-F for Corrosion Control, Francis J. Honn, M. W. Kellogg Co.

6 New England Section. Corrosion by Portable Waters, Samuel Jacobson, New Haven Water Co.

7 Pittsburgh Section. National president's and past section chairmen's night. Gateway Center.

12 Houston Section, John's Restaurant, Houston. Corrosion Problems in the Communications Industry, W. W. Elley, Southwestern Bell Telephone Co., San Antonio.

19 Chicago Section. Nickel Alloys and Their Uses, T. F. Drantz, Haynes Stellite Co.

19 Cleveland Section. Atomic Power for Industry.

20 Greater Boston Section. Design Against Corrosion, F. L. LaQue, The International Nickel Co., Inc.

21 Detroit Section. Joint meeting with The Electrochemical Society. Milton Stern, Electro Metallurgical Corp., Niagara Falls: Fundamentals of Electrode Processes in Corrosion.

28 Sabine-Neches Section. Corrosion Problems in the Chemical Industry, Little Mexico Restaurant, Orange, Texas.

March

4 North Texas Section, Dallas. Design for Corrosion, F. L. Whitney, Jr., Monsanto Chemical Co., St. Louis.

7 Pittsburgh Section. Tour of U. S. Steel Corp. Research Center.

18 Lehigh Valley Section, Keystone Trail Inn, Allentown, Pa. Fretting Corrosion, T. P. May, International Nickel Co., Inc. (Tentative)

19 Cleveland Section. Copper and Its Alloys, Including Aluminum Bronze for Use in Corrosive Environments, I. S. Levinson, Ampco Metals, Inc.

26 Central Oklahoma Section.

28 Sabine-Neches Section, Little Mexico Restaurant, Orange, Texas. Corrosion in Recirculating Cooling Water Systems.

28 Kanawha Valley Section, Kanawha County Airport, Charleston, W. Va. Report on Kanawha Valley Coordinating Committee on Corrosion and round table discussion on cathodic protection.

Jelen Discusses Economics At AIChE-NACE Session

A joint meeting of the American Institute of Chemical Engineers and Genessee Valley Section NACE held December 5th was atended by approximately 100 persons from both associations. Frederic C. Jelen, of Solvay Process Division, Allied Chemical & Dye Corp. spoke on Comparison of Alternatives by Capitalized Cost.

Shreveport Section Elects E. H. Sullivan

E. H. Sullivan, United Gas Pipe Line Co., Shreveport has been elected chairman of Shreveport Section for 1957. Mr. Sullivan, a member of NACE since April, 1945 and continuously engaged in corrosion work since that time, also is active in committee T-1 and is a member of the Seahorse Institute. He is a 1939 graduate in Engineering Administration from Texas A & M College and a registered Texas professional engineer.

Sullivan

Other officers elected by the section were L. B. Morrow, senior corrosion engineer for Interstate Pipe Line Company, Shreveport and a registered Louisiana professional engineer, vice-chairman; L. B. Irish, Irish Engineering Service, Shreveport, for five years corrosion engineer with Arkansas-Louisiana Gas Co. before starting his own company, secretary. Treasurer is John Stone, Sunray-Midcontinent Oil Co., formerly with Magnolia Petroleum Co. and Wright Chemical Company.

Sidney E. Trouard, corrosion engineer with New Orleans Public Service, Inc. was scheduled to talk to the January 15 section meeting on "Deep Ground Beds for Cathodic Protection."

Middle East Corrosion Problems Are Discussed

Corrosion problems and solutions to corrosion problems peculiar to the conditions existing in the Middle East were explained and illustrated with color slides before a meeting at Mellon Institute of Pittsburgh Section January 3. The meeting followed an informal dinner at the Royal York Hotel. L. P. Sudrabin, Technical Director of Electro Rust-Proofing Corp., Belleville, N. J. was the speaker before 48 members and guests.

After the routine business of the section R. B. Hoxeng, United States Steel Corp., general chairman of the Northeast Region meeting to be held in Pittsburgh during the fall related current activities of subcommittee chairmen.

Mr. Sudrabin, long active in NACE and other technical groups has returned recently from several months' consulting on corrosion problems in petroleum production equipment, pipelines, process equipment, marine structures and ships in Lebanon, Syria, Jordan, Saudi Arabia and in the Caribbean. Unique corrosion problems were described (including unusually severe buried pipeline penetration in remote arid regions with soil resistivities of over 200,000 ohm centimeters) which annually cause losses of several million dollars a year.

Cleveland Hears Fontana

M. G. Fontana of Ohio State University presented a paper on Corrosion and Its Prevention to approximately 60 members and guests attending the December 18 meeting of Cleveland Section.

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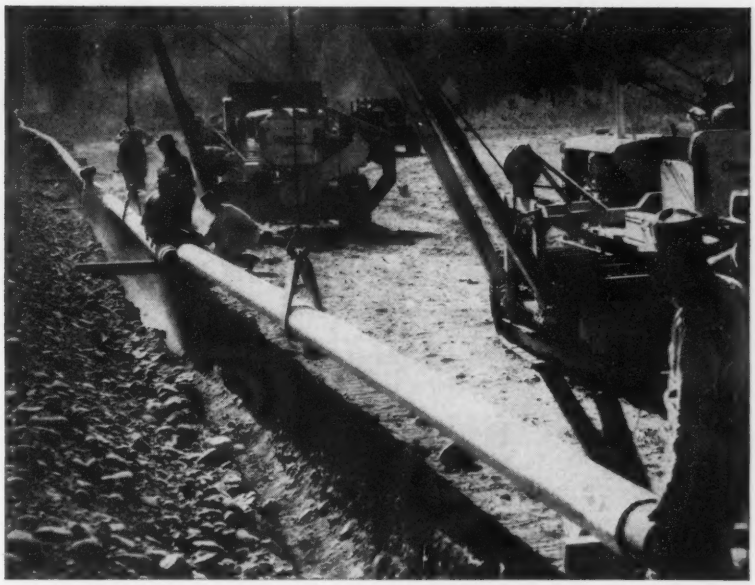

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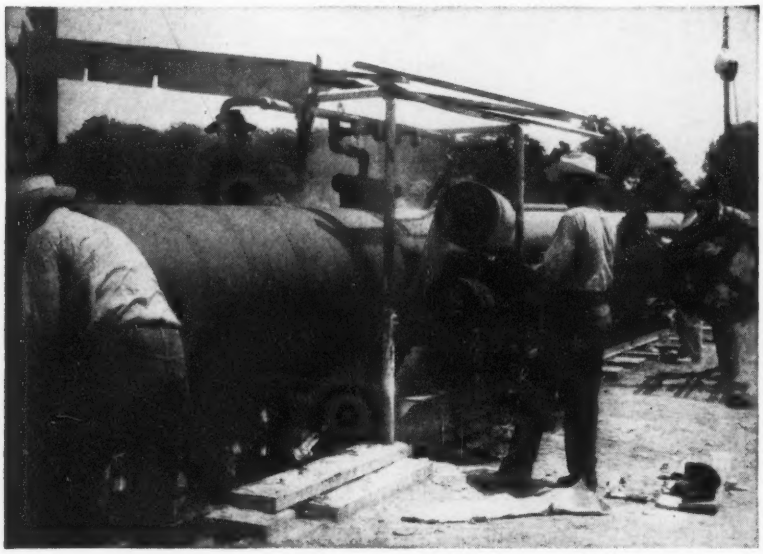
Nominations for the 1958 Whitney and Speller Awards

The Willis Rodney Whitney Award is given in recognition of public contributions to the science of corrosion. A contribution to science is defined as the development of new information or the development of a more satisfactory theory which contributes to a more fundamental understanding of corrosion phenomena.

The Frank Newman Speller Award is given in recognition of public contributions to corrosion engineering. A contribution to engineering is defined as the development or improvement of a method, apparatus or material by which the control of corrosion is facilitated or made less costly.

Nominations may be made by local sections or may be proposed directly to the Chairman of a Region by individual members up to June 1, 1957. In any case, nominations should be accompanied by an appropriate statement of the basis of the proposal.

Procedure in the Selection of Persons to Receive these awards was published beginning on Page 98 of the March, 1956 issue of Corrosion, or anyone interested may get a copy by writing to Central Office NACE, 1061 M & M Bldg., Houston 2, Texas.



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Toronto Section's Annual Meeting Set Feb. 28–Mar. 1

The 1957 annual meeting of Toronto Section will be held Thursday and Friday, February 28-March 1 in the Fountain Room of the King Edward Hotel, Toronto.

A tentative program has been proposed to include: Fundamentals of Corrosion, by Dr. Wetmore, University of Toronto; a talk by an engineer of Trans-Canada Pipe Line and a talk on corrosion control in underground structures, sewage disposal plants, water works systems, chemical plants and refineries.

Also considered are short talks on application of and merits of Transite pipe, pressure concrete pipe, cast iron pipe and steel pipe.

Central Oklahoma Section Elects E. G. Stevens

E. G. Stevens, Dowell, Inc., Norman, Okla. has been elected chairman of Central Oklahoma Section for 1957. Also elected were R. V. James, University of Oklahoma, Norman, vice-chairman; M. F. Hill, Jr., Greene Bros., Inc., Oklahoma City, secretary-treasurer and Dan H. Carpenter, Aquaness Dept., Atlas Powder Co., Oklahoma City, trustee.

The December 18 meeting of the section, attended by approximately 25 members and guests, was held at the Tropical Cafeteria, Oklahoma City.

Frank James, Allied Paint Mfg. Co. spoke on Coal Tar-Epoxy Combinations which aroused much interest and was followed by a very active discussion period. The next regularly scheduled meeting was January 22 when Frank B. Burns of Kerr McGee Industries was scheduled to speak on Field Coating and Wrapping Pipe Lines.

Teche Section Names O. L. Bassham Chairman

The following were elected officers of the Teche Section for 1957 and assumed office January 31: O. L. Bassham, Tretolite Company, chairman; J. F. Shofner, Aquaness Corp., vice-chairman; Frank L. Rhoades, Jr., Otis Pressure Control, Inc., secretary-treasurer, and George M. Harper, Union Oil Company of California, trustee.

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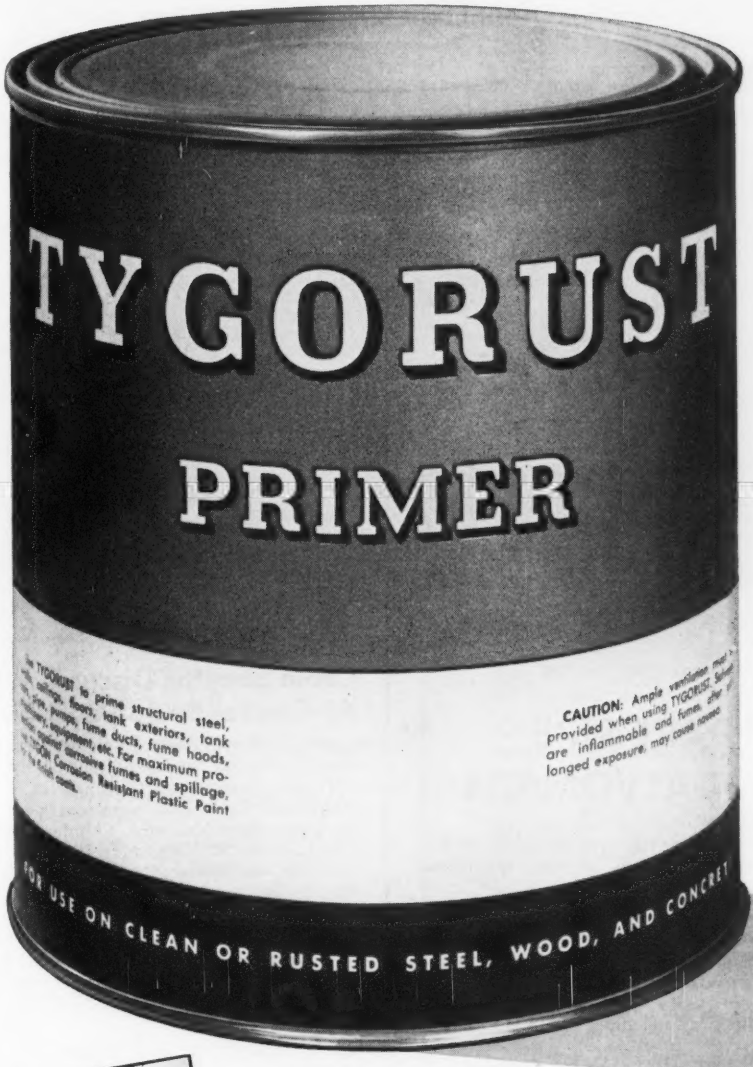

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Sprayed Coatings Covered In Talk at Detroit

Approximately 35 members and guests at the December 13 meeting of Detroit Section heard S. J. Oechsle, Jr., Metalweld Inc., Philadelphia discuss Sprayed Coatings—(Metallic and Non-Metallic) to Prevent Corrosion. Mr. Oechsle dealt with the history, application and uses of metallic spray and organic and ceramic coatings, emphasizing their application and utilization.

It was announced that the following officers were elected to serve the section during 1957: Walter R. Cavanagh, Parker Rust Proof Company, chairman; Robert P. Marshall, Saran Lined Pipe Company, vice-chairman and L. W. Gleekman, Wyandotte Chemical Company, treasurer.

Houston Section to Hear Discussion by W. W. Elley

Corrosion Problems in the Communications Industry will be the topic of a talk by W. W. Elley, Southwestern Bell Telephone Co., San Antonio before a meeting of Houston Section February 12.

At the January 8 meeting a panel discussion on "Corrosion by Recirculating Cooling Water," was carried on by Charles P. Dillon, Carbide and Carbon Chemicals Co., Texas City, moderator; A. R. Pettyjohn, Union Carbide and Carbon Co., Texas City and L. M. Rogers, Carbide and Carbon Chemicals Co., Texas City.

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NATIONAL, REGIONAL MEETINGS and SHORT COURSES

1957

Mar. 11-15—NACE Annual Conference, Kiel Auditorium, St. Louis, Missouri.

May 20-22—Northeast Region Corrosion Control Conference, Syracuse University, Syracuse, N. Y.

Oct. 1-4—North Central Region, Chicago, Sherman Hotel. Exhibition.

Oct. 1-4—South Central Region, Oklahoma City, municipal auditorium. Exhibition.

Nov. 12-14—Northeast Region Fall meeting, Pittsburgh, Pa.. Penn-Sheraton Hotel.

1958

Mar. 17-21—NACE Annual Conference, Civic Auditorium, San Francisco, California.

October 5-8—Northeast Region, Somerset Hotel, Boston, Mass.

October 20-24—South Central Region. New Orleans, Roosevelt Hotel.

1959

NACE Annual Conference, Sherman Hotel, Chicago, Illinois.

SHORT COURSES

April 2-4—University of Oklahoma, Norman and Central Oklahoma Section NACE.

February 13-15—Eighth Annual Tulsa Corrosion Short Course, February 13-15, Mayo Hotel, Tulsa.

Cable Sheaths Discussed At Greater Boston Section

At Greater Boston Section's December 19 meeting approximately 56 members and guests heard Vernon Pike, Bell Telephone Laboratories present a paper on Electrolytic Voltages of Underground Lead Cable Sheaths. Mr. Pike's presentation was followed by an active discussion period with questions from many guests connected with the utilities industry.

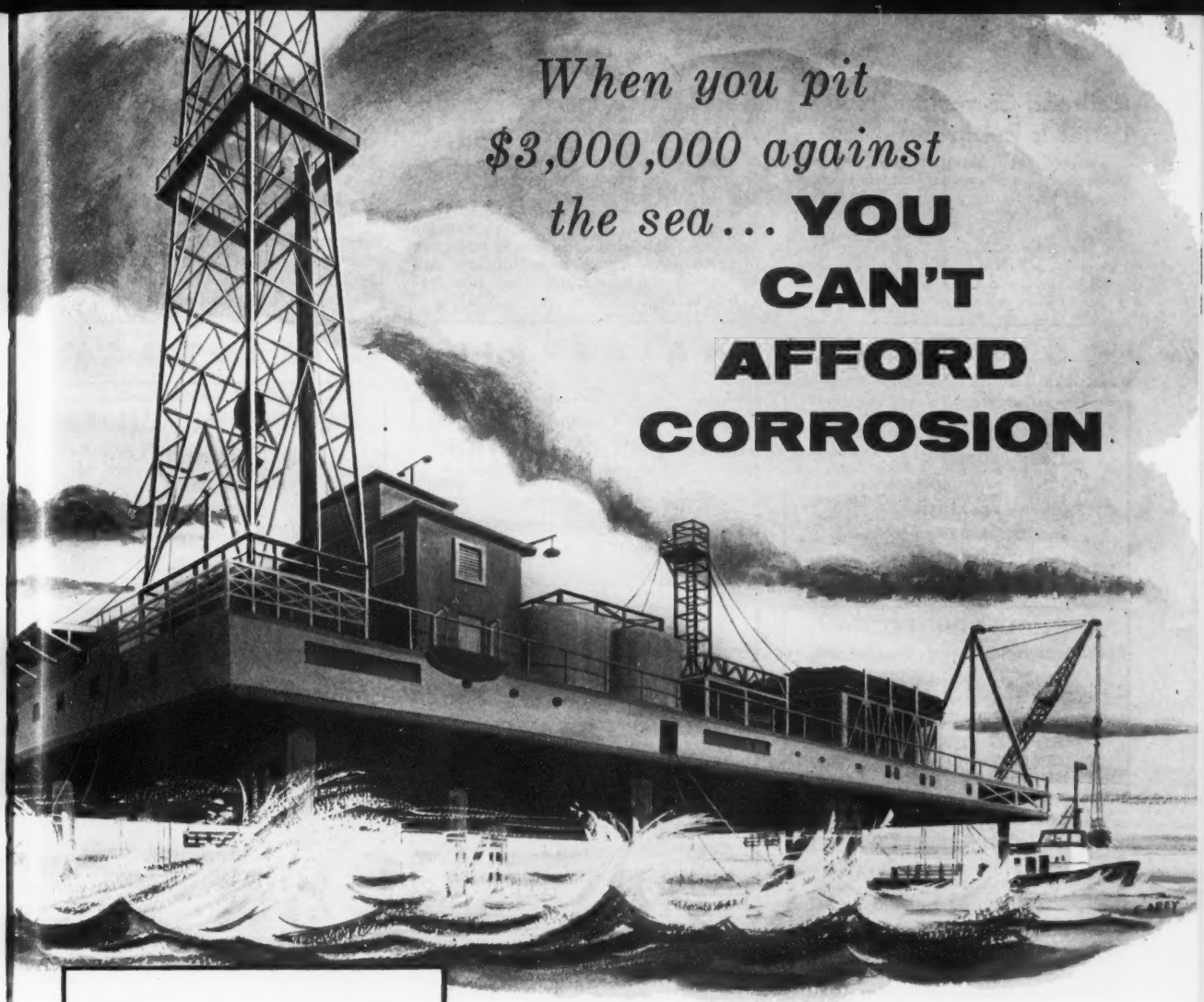
Next regular meeting of the section will be Wednesday, February 20 at Hotel Beaconsfield, Brookline, Mass.

S. F. Spencer Is Elected

The following officers were elected for 1957 by Philadelphia Section: S. F. Spencer, Keystone Shipping Company, chairman; Walter W. Burton, General Chemical Div., Allied Chemical & Dye Corp., vice-chairman, and Robert S. Mercer, Pennsalt Chemicals, secretary-treasurer.

Illinois U. Short Course

A short course on corrosion control will be held December 9-13 at the University of Illinois, Urbana.



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Railroad Corrosion News Letter Is Published

Articles on coatings, stainless steel passenger cars, typical railroad corrosion problems, polyethylene linings, austenitic stainless steels, fuel oil ash corrosion and others are included in Vol. 4, No. 2 of the Railroad Corrosion News Letter issued November 1956. The publication is issued by T-3E on Railroads. S. K. Coburn is editor.

Radioactive Tracers Topic At Los Angeles Meeting

Radioactive Tracer Techniques in Corrosion was the scheduled topic of a talk by M. T. Simnad, General Atomic Division, General Dynamics Co. at a January 23 meeting of Los Angeles Section. Scheduled also was installation of new Western Region officers and nomination of new officers for Los Angeles Section.

Titanium Conference Set

A five-day conference on titanium to be presented by the recently organized Metals Engineering Institute of American Society for Metals will be featured on the technical program of the 10th Western Metal Congress, March 25-29, Ambassador Hotel, Los Angeles. Anton D de S. Brasunas, director of the institute, has charge of the program.

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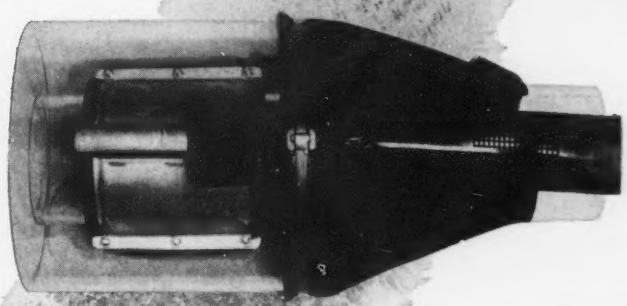
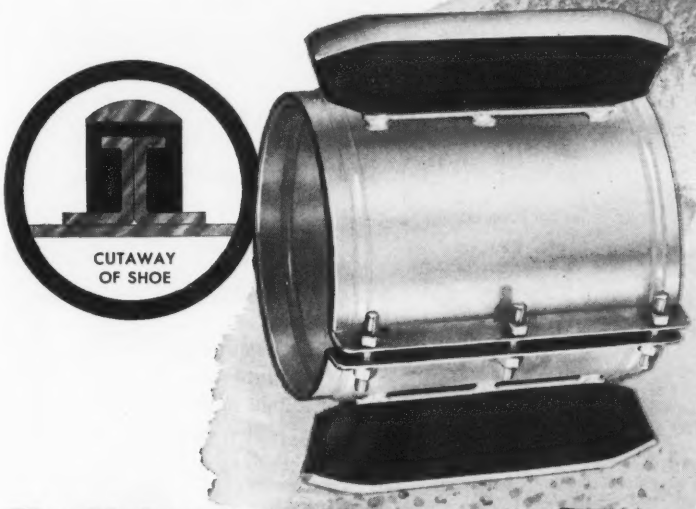




The Maloney Model 55 Crossing Insulator

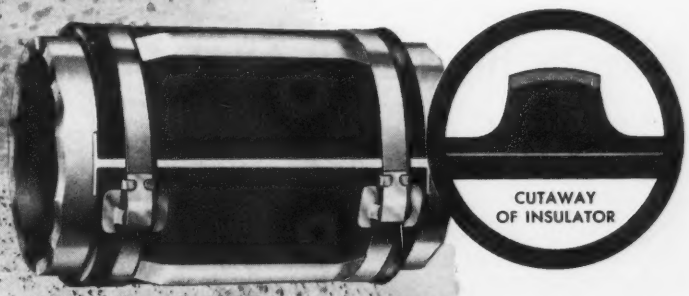
For all Sizes of Pipe

These insulators have superior insulation qualities because of the low moisture absorption and the long life compounded into the neoprene. The wide steel, sled type runners make installation easy. The extra wide band affords a positive grip. Bonded metal-to-neoprene-to-metal, the runner insulates and also permits flexibility to compensate for pipe shifting. Ribbed neoprene lining can be furnished if desired.

The Maloney Model 56 Casing Insulator

Manufactured in sizes from 2" through 12"

Manufactured with neoprene, which is vulcanized to the steel band core and to the rounded steel runners, there is no place to "short-out" between the casing and the carrier line. The steel core is completely surrounded with neoprene and is bonded under heat and pressure to give the same strength as on army tank tread blocks.



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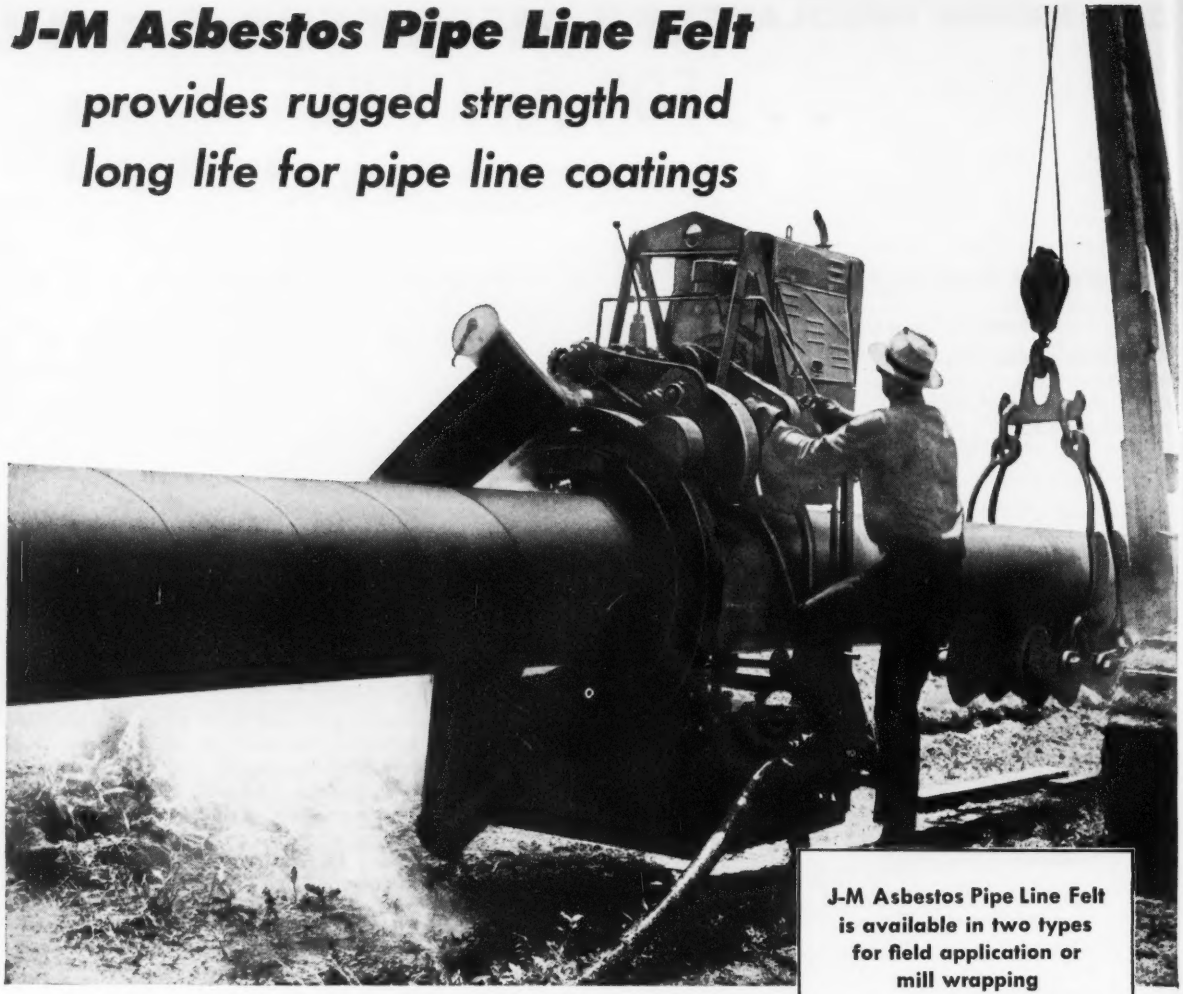
J-M Asbestos Pipe Line Felt

provides rugged strength and long life for pipe line coatings



Permits high-speed wrapping and effective protection for enamels

Johns-Manville Asbestos Felt gives pipe line coatings the rugged strength that is needed to guard the enamel from years of soil action. It forms a *stable* coating to reduce the hazards of pipe line corrosion leaks and provides a sound foundation when cathodic protection is used. Inorganic asbestos felt is the only wrapper that has survived more than half a century of actual service conditions in all types of soils.

J-M Asbestos Pipe Line Felt acts as a continuous sheath over the enamel . . . guarding the coating from the effect of the shifting grip of the soil as it expands and contracts due to alternate wetting and drying. It resists the destructive action of bacteria, fungi and soil chemicals, thus assuring long life to pipe line coatings.

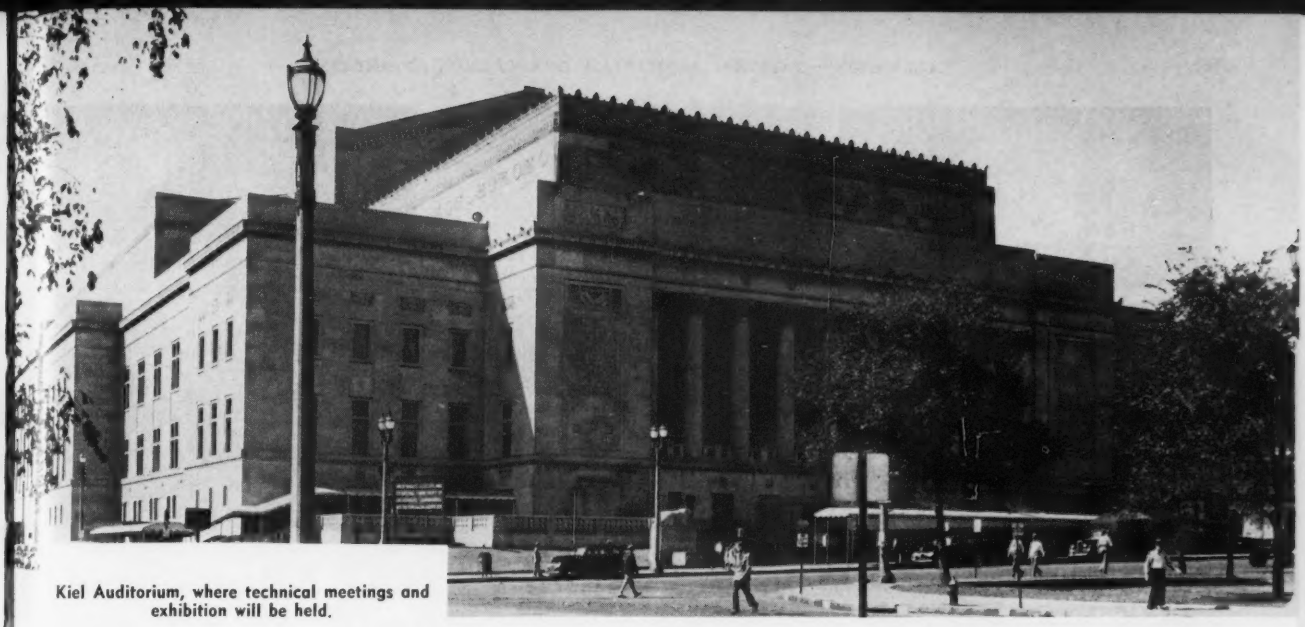
J-M Asbestos Pipe Line Felt is available in two types for field application or mill wrapping

Transhield® Asbestos Pipe Line Felt—for average soil conditions.

#15 Asbestos Pipe Line Felt—heavy-duty material for severe soil conditions where a heavier material is desired.

For further information about Johns-Manville Products for Pipe Line Protection, write to Johns-Manville, Box 14, New York 16, N. Y., in Canada, Port Credit, Ontario.

JOHNS-MANVILLE JM PRODUCTS **Johns-Manville** ASBESTOS FELT FOR PIPE LINE PROTECTION



Kiel Auditorium, where technical meetings and exhibition will be held.

68-Paper Technical Program Opens March 11

Advance Program Mailed To Members of NACE

An advance program for the 13th Annual Conference and Exhibition was mailed during January to all NACE members. The program covered arrangements on the date of printing. Some changes are anticipated before the official conference program is prepared.

The technical program is as follows:

Tuesday, March 12
Morning
Oil and Gas Production Symposium
Chemical Industry Symposium—Part 1
Afternoon
Refinery Industry Symposium
Protective Coatings Symposium
Pipe Line Group Discussions
Educational Lecture No. 1

Wednesday, March 13
Morning
Corrosion Principles Symposium
Chemical Inhibitors Symposium
Afternoon
General Corrosion Symposium—Part 1
Chemical Industry Symposium—Part 2
Cathodic Protection Symposium
Educational Lecture No. 2

Thursday, March 14
Morning
Pipe Line General Symposium
Plastic Symposium
High Temperature Symposium
Afternoon
Power and Communications Symposium
High Purity Water Symposium
General Corrosion Symposium—Part 2
Educational Lecture No. 3

Friday, March 15
Morning
General Corrosion Problems Roundtable
Pipe Line and Underground Corrosion Problems Roundtable.

•

During the decade 1945-54 CORROSION's Technical Section included 3591 pages of text, tables and photographs. All articles are topically indexed in the 10-Year Index to CORROSION.

Note This Important St. Louis Meeting

It is important to NACE members to know what is going on in their association. The officers and directors of NACE urge all members to make a note of this important time and date:

Wednesday, March 13
11:30 a.m.
Kiel Auditorium
Assembly Hall No. 1
2nd Floor, Northeast

The association's 1957 General Business Meeting will be held at that time and place. All NACE members are urged to attend to hear reports by NACE president, treasurer, executive secretary, Technical Practices Committee chairman, Publication Committee chairman, Policy and Planning Committee chairman, Regional Management Committee chairman.

- ***Certain actions of the NACE Board of Directors will be submitted for ratification by the membership.***

Plan now to attend!

Registration Hours at St. Louis Are Announced

Registration arrangements have been made for the 13th Annual NACE Conference as follows:

Sunday, March 10—Mezzanine Floor, Sheraton-Jefferson Hotel: 2 pm-5 pm.
Monday, March 11—Mezzanine Floor, Sheraton-Jefferson Hotel: 8 am-5 pm.
Tuesday Through Thursday, March 12-14—Kiel Auditorium: 9 am-5 pm.
Friday, March 15—Kiel Auditorium: 9-10 am.

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Subscribers to the NACE Corrosion Abstract Punch Card Service may supplement classifications of abstracts by preparing duplicate cards of abstracts interesting to them.

•

Libraries of educational institutions may subscribe to CORROSION for $4 a year.

Some Technical Committees to Convene Sunday

A symposia schedule with 68 technical papers has been arranged for the 13th Annual Conference and Exhibition at St. Louis, March 11-15. The technical schedule is so full that some technical committees will meet all day Sunday, March 10, in effect extending the conference another day.

In addition to this there will be two round table sessions, each three hours in length and a demonstration for pipeliners of the effects of various conditions affecting corrosion of metals underground as reflected in electrical potential measuring instruments.

Simultanious with the technical program the annual exhibition will be held beginning Tuesday morning.

There will be ample after-hours activity. The usual Fellowship Hour will be held; a cocktail party will precede the annual banquet, which will include informal dancing and entertainment, and a full program for ladies attending has been arranged.

The technical program reflects in its diversity the broad interests of persons concerned with corrosion control, in its theoretical, applicatory and management aspects. Every effort has been made to arrange the program to minimize conflicts among simultaneous sessions of related subject matter. The degree of success in this aim has been limited not only by the magnitude of the formal technical sessions, but by the number and diversity of technical committee meetings.

A meeting of the Inter Society Corrosion Committee will be held.

Meetings of the association's standing committees: Regional management, policy and planning, publication and its subcommittees, editorial review and abstract, also will be held. As has been the custom in years past, several NACE groups at the regional or other level may take the opportunity presence of so many members at the conference offers and schedule meetings.

Fun, Music and Humor to Feature Banquet Entertainment

EXHIBITION HOURS SET

Hours during which the 13th Annual NACE Exhibition at Kiel Auditorium, St. Louis will be open to visitors are: Tuesday, March 12 through Thursday, March 14—9 am to 5 pm. Friday, March 15—9 am to Noon.

Topical indexing of the 629 articles published in CORROSION's Technical Section 1945-54 is provided in the 10-Year Index to CORROSION.

Corporate Members' Lunch At St. Louis Set March 12

A meeting of corporate members of the National Association of Corrosion Engineers has been scheduled for 12:15 pm on Tuesday, March 12 during the 13th NACE Annual Conference and Exhibition. W. F. Fair, Jr., NACE president has asked corporate members to be prepared to make suggestions during the luncheon on ways in which NACE can be made more valuable to its membership.

Dance Music to Be Played During Annual Event

Dance music will be heard during the 13th Annual Banquet to be held in the Gold Room of the Sheraton-Jefferson Hotel, St. Louis on the evening of Wednesday, March 13. A full program of entertainment has been arranged.

Ross

Holt

The usual program will be held, including the presentation of the Whitney and Speller Awards and the Young Author Award. Informal dancing will follow the dinner.

The entertainment will include routines by the Varju Brothers (See illustrations at top of page, left), novelty acrobatics and contortions by Chai and Somay, a Chinese young man and his wife (center) while Dick Balsamo, organist (right) will play the organ at intervals between 7 and 9 pm. Also scheduled to perform is the comedy team of Arren and Johnny Broderick. Miss Arren caricatures operatic prima donnas while Mr. Broderick assists on the piano.

Master of ceremonies for the entertainment will be Bob Holt, who also is a mimic.

A cocktail hour will precede the banquet.

Bonnie Ross leads the dance orchestra.

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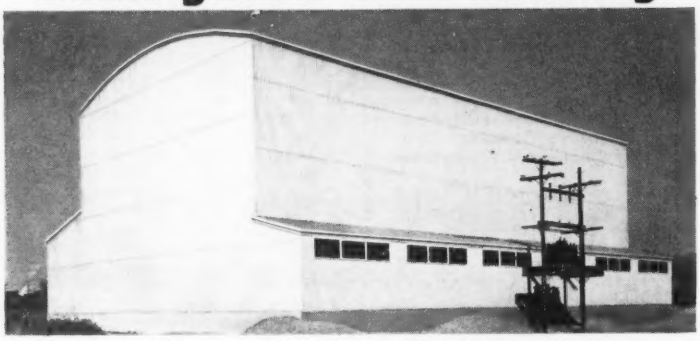
During the decade 1945-1954 CORROSION's Technical Section included 3591 pages of text, tables and photographs. All articles are topically indexed in the 10-Year Index to CORROSION.

Paint guards steel building



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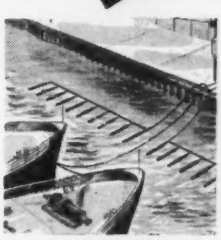
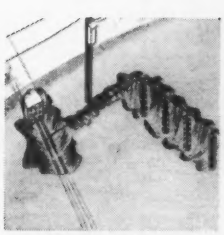
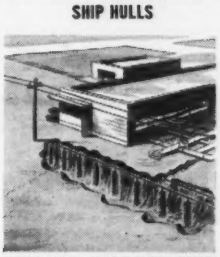
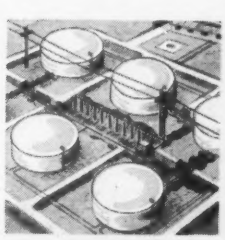
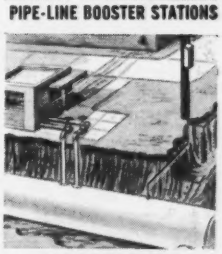

SHIP HULLS


LEAD-COVERED CABLES


PIPE-LINE BOOSTER STATIONS


TANK FARMS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Mange

Marshall

Mattsson

McGeary

McGlasson

Meyer

Riggs

Sudbury

Walton

General Corrosion Symposium to Include Two Afternoon Sessions of 4 Papers Each

Two afternoon sessions will be held for the presentation of eight papers during the General Corrosion Symposium at St. Louis. E. G. Holmberg, International Nickel Co., Inc., Detroit, symposium chairman announced the following seven papers and their authors and said that the eighth paper will be committed soon.

The General Corrosion Symposium will be held during the afternoons of March 13 and 14. Titles of papers, authors' names and abstracts released by Mr. Holmberg follow:

Corrosion of Galvanized Steel in Contact with Concrete Containing Calcium Chloride by Clarence E. Mange, C. E. Mange Development Laboratory, St. Louis.

The severe and rapid corrosion of galvanized steel sheets, used as permanent forms in the construction of concrete floor and roof slabs has been investigated.

The use of calcium chloride as a cold weather admixture for concrete has been accepted generally and the use of galvanized steel sheets as permanent forms for concrete slabs has been approved on innumerable structures. Under certain conditions, however, the combination of galvanized steel in contact with concrete containing calcium chloride has resulted in rusting and perforation of the metal forms.

Of primary importance in these corrosion failures, is the addition of excess water in the concrete and the sealing of this water within the slab. Application of heat, either by radiant coils or otherwise, seems to accelerate the reaction.

The Compatibility of Aluminum with Alkaline Building Products by C. J. Walton, F. L. McGeary and E. T. Englehart, Alcoa Research Laboratories.

During the past 25 years Alcoa Research Laboratories has conducted tests to determine the performance of aluminum alloys in contact with a wide variety of alkaline building materials. Results of these are summarized and discussed in conjunction with many service experiences. In the recent past, several specific investigations on the effects of concrete on aluminum alloys have been conducted and these are described in detail. Included are the results of evaluations on admixtures, cathode size in galvanic circuits, complete and cyclic immersion in water and stray currents.

These studies indicate that aluminum alloys exhibit a good resistance to alkaline building products under normal conditions of service.

Corrosion of Iron by Solid Solution in Its Sulfides by F. H. Meyer, O. L. Riggs, R. L. McGlasson and J. D. Sudbury.

An end product of the corrosion of iron in aqueous H_2S media has been recently identified as a crystalline material, Fe_9S_8 (kansite). Kansite appears to form as a terminal product from a sequence of discrete iron sulfides—pyrites, marcasite, melnikovite, smythite, pyrrhotite, troilite and hydrotroilite—which develop from the continuous solid solution of iron and/or sulfur with a preceding or succeeding sulfide member of the sequence.

The formation of sulfides increasingly rich in iron cannot be explained satisfactorily by the electrochemical theory of corrosion. This theory fails also to account for the acceleration of H_2S corrosion due to the formation of corrosion scales.

Solid solution of iron in iron sulfide products of electrochemical corrosion is presumed by the authors to provide a secondary corrosion source in addition to the established electrochemical corrosion source. The rates of diffusion of iron sulfides will be intensified because some, and possibly all, of them are defective structures.

This kind of postulated mechanism has been used previously to describe the solid solution of iron into and diffusion through iron oxide corrosion products in high temperature oxidation systems. The outcome in this case, too, is a multiple layer formation of a sequence of discrete iron oxides; here, however, subsequent layers become increasingly poor in iron.

The validity of the hypothesis concerning a secondary H_2S corrosion source was checked by determining the corrosion rates of mild steel specimens treated with dry sulfides.

Corrosion of Metals in Tropical Environments by Allen L. Alexander, Naval Research Laboratory.

A long-term investigation is in progress in the Panama Canal Zone to study the corrosion rates and characteristic of fifty metal types exposed to five natural tropical media. This paper is a report on the behavior of six metals in the program during the first half of the contemplated sixteen year program. Replicate panels of lead, structural steel, aluminum, copper, zinc and nickel were removed from exposure after

(Continued on Page 104)

BIOGRAPHIES

ALLEN L. ALEXANDER—Acting Associate Superintendent of the Chemistry Division, Naval Research Laboratory and head of the laboratory's protective coating branch, Dr. Alexander holds BS, MS and PhD degrees from University of North Carolina. He is active in ASTM, ACS and is a member of the Federation of Paint and Varnish Production Clubs, Washington Academy of Sciences and Research Society of America. He has been chairman of the Baltimore Section, NACE and has headed programs at national NACE meetings and Western Region short courses.

E. T. ENGLEHART—Has worked on fundamental and practical problems of corrosion and corrosion-prevention of aluminum alloys as a member of the Chemical Metallurgy Division, Alcoa Research Laboratories, Aluminum Company of America. He holds a BS in chemistry from Pennsylvania State University, 1943, when he joined Alcoa. Author of several papers on the corrosion of aluminum alloys, he is a member of NACE.

T. P. HOAR—Lecturer in Metallurgy, Cambridge University, England, he is a consultant to several large companies on metallurgical problems including corrosion. He began research on fundamental corrosion processes with Ulick Evans after graduation from Cambridge in 1930, receiving a PhD for this work in 1933. He made a series of investigations on corrosion of steel, tin and tinplate for International Tin Research and Development Council and during 1939-45 was occupied with research and development programs in corrosion for British military service departments and for industrial concerns.

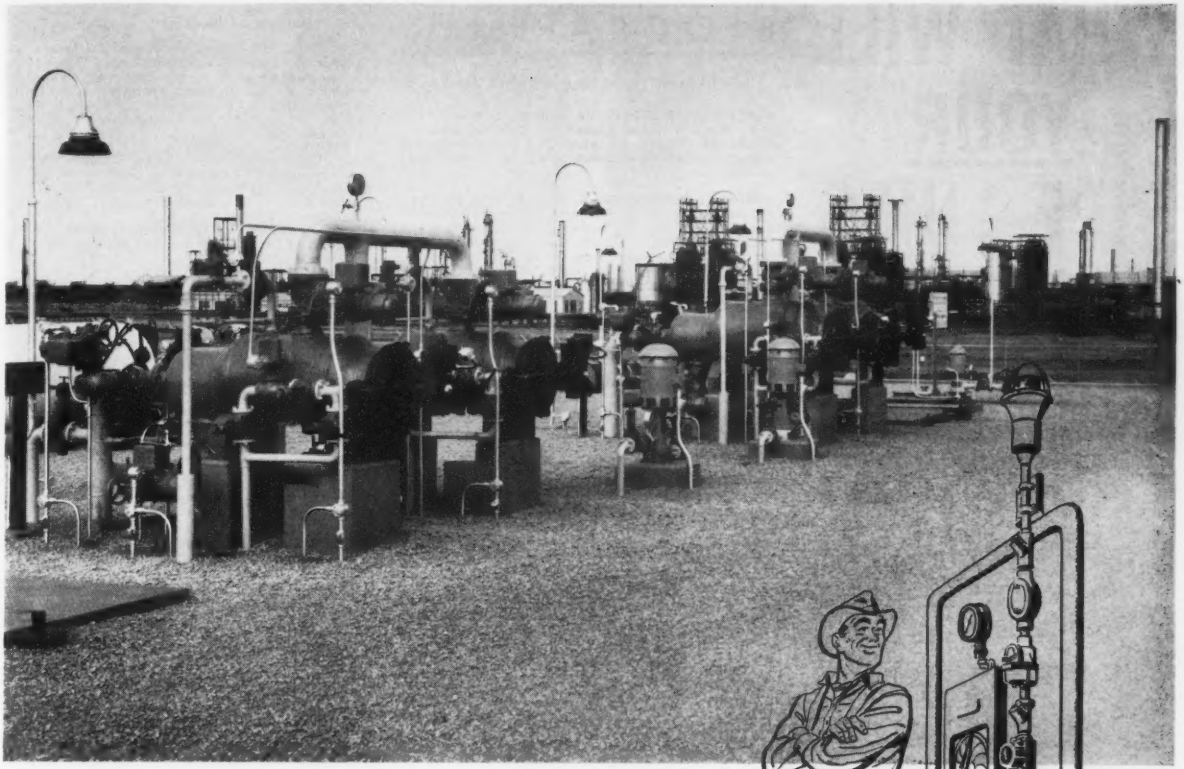
CLARENCE F. MANGE—A consultant on metal finishing and corrosion, he is a charter member of Greater St. Louis Section NACE. He has a BS and MS from Washington University in 1922 and is a registered professional engineer of Missouri. He is a member of numerous engineering and trade organizations.

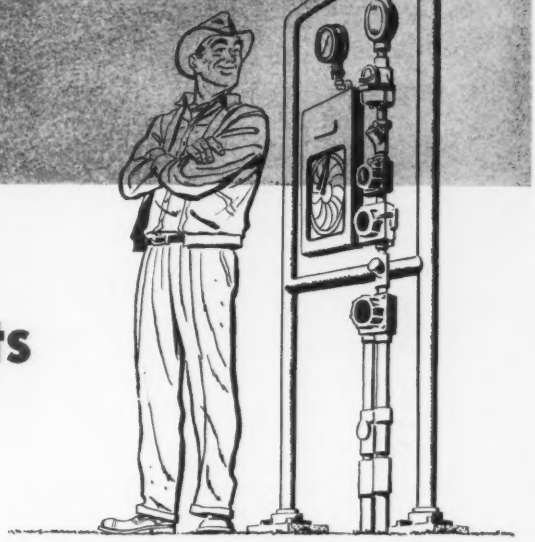
T. MARSHALL—Senior metalurgist at Dominion Laboratory, Department of Scientific and Industrial Research, New Zealand, he holds bachelor degrees in engineering and science from Otago University, is an Associate of the Institution of Metalurgists, and of the New Zealand Institute of Chemistry and a member of AIME. He works principally in corrosion research.

EINAR MATTSSON—Chief of the Corrosion Research Section at AB Svenska Metallverken, Vasteras, Sweden. During the current academical year Dr. Mattsson holds a senior fellowship at the University of Pennsyvania where he is continuing his studies in collaboration with Prof. J. O'M. Bockris. He received the degree of Teknologie Licentiat (equivalent to PhD at most United States universities) from the Royal Institute of Technology, Stockholm in 1955 after studies on the electrode kinetics of metals.

F. L. McGEARY—Has been working on corrosion of aluminum alloys, with special attention to the effect of non-metallic materials as a member of Chemical Metallurgy Division, Alcoa Research Laboratories, Aluminum Company of America since his discharge

Continued on Page 102)





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BIOGRAPHIES

(Continued From Page 100)

from the Navy in 1946. He expects to receive soon a BS in metallurgical engineering from Carnegie Institute of Technology where he attends evening classes. Among other organizations he is a member of NACE.

ROBERT L. McGLASSON—A year's work in the quality control laboratory, Boeing Airplane Co., Wichita, Kan. aroused Mr. McGlasson's present interest in physical metallurgy. For the past four years a major portion of his work has been on corrosion metallurgy, with major emphasis on corrosion problems associated with oil production, as a metallurgist in the Development and Research Department of Continental Oil Co. He has a BS from Northwestern State College, Alva, Okla. in physics and mathematics.

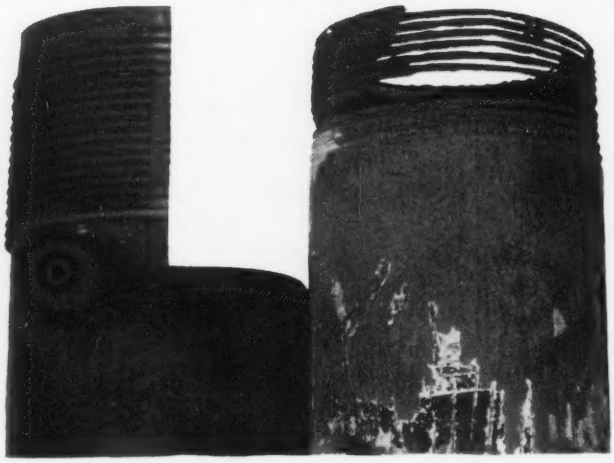
F. H. MEYER—Associate Research Physicist, Continental Oil Co., Ponca City, Okla. A member of the American Physical Society, the American Crystallographic Association and the American Chemical Society, he has a science degree from the College of the City of New York and an MS in physics from Polytechnic Institute of Brooklyn.

O. L. RIGGS, JR.—As a member of Continental Oil Company's Research Department since February 1952, he has worked on corrosion chemistry and related problems. He has a BS in chemistry from Eastern Nazarene College, Boston, Mass. and was a teacher in Ohio public schools for two years. He is a member of NACE.

J. D. SUDBURY—Research Group Leader, Development and Research Department, Continental Oil Co. he holds a PhD in physical chemistry, University of Texas, 1949. He is a member of NACE among other engineering organizations and for the past eight years has been active in oil well corrosion research. He is active in NACE and author of many papers on corrosion control.

C. J. WALTON—Assistant Chief of the Chemical Metallurgy Division, Alcoa Research Laboratories, he joined Alcoa in 1931 and was promoted to his present position in 1946. His entire service with Alcoa has been concerned with corrosion and stress corrosion cracking of aluminum alloys, particularly in natural environments. He has a degree in metallurgical engineering from Carnegie Institute of Technology Evening School (1942). He is a member of NACE and ASM and is author of several technical papers.

. . . BECAUSE *FIBERCAST* LINE PIPE



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ON THE LEFT: Fibercast tubing, after **one year's operation.**
ON THE RIGHT: Plastic coated steel tubing, after **three month's operation!**

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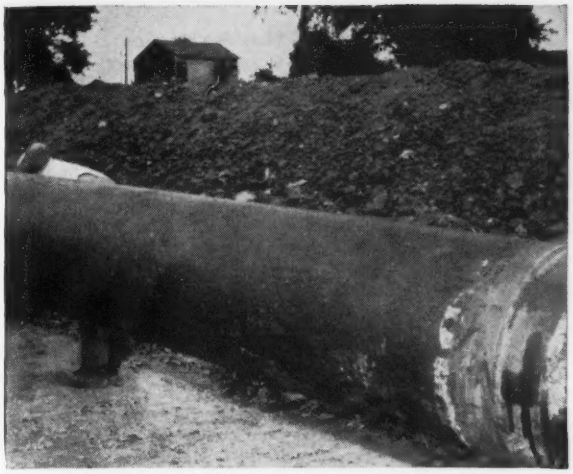
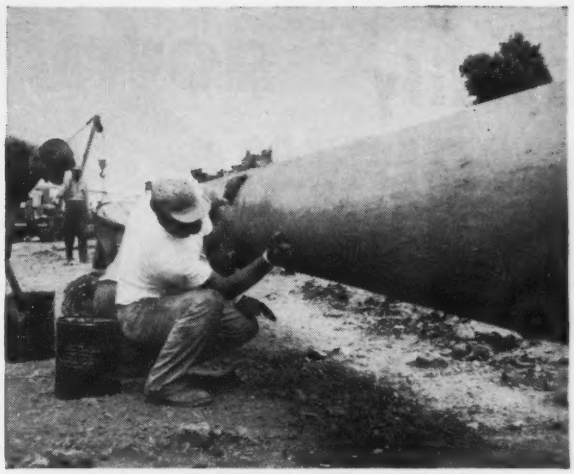
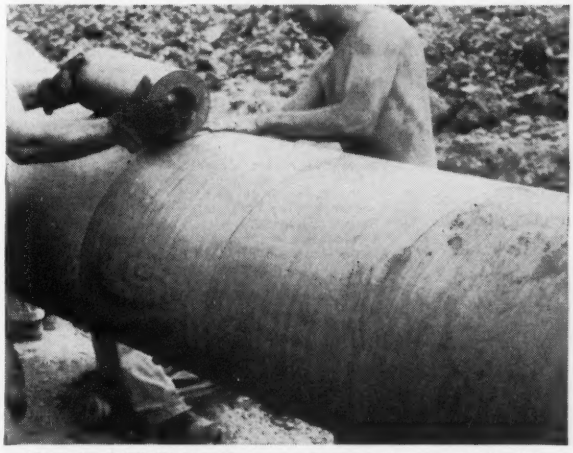


Pipe, buried for 25 years, is good as new



Applying NO-OX-ID "GG" over the cleaned surface



Next, No. 4 NO-OX-IDized wrapper for protection against abrasion

Finally, NO-OX-ID Filler Red "C," a seal coat, completes protection

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NACE Has No Copies Of Conference Papers

No copies of papers presented at the 13th Annual Conference are available from NACE. Authors of papers sometimes prepare preprint versions of their papers in which cases copies may be secured from authors. Persons interested in technical material presented are urged to consult CORROSION in which all papers approved by the NACE Editorial Review Subcommittee and the editor of CORROSION will be published after they are approved. Non-members of NACE may subscribe to CORROSION at rates indicated in this issue.

General Corrosion–

(Continued From Page 100)

periods of one, two, four and eight years. Following this, measurements were made on the specimens, the results of which describe their resistance or susceptibility to corrosion in five natural tropical environments. Significant measurements include tensile changes, weight loss, pitting attack, dimensional change and visual change. Some description of the more prominent types of corrosion occurring when the metals are exposed to sea water, mean tide level (sea), fresh water clean atmosphere (high rainfall) and salt (sea shore) atmosphere. In addition some novel results are presented relative to attack of a marine organism on magnesium.

Stress Corrosion Cracking of Austenitic Stainless Steels by Geothermal Steam by T. Marshall, Dept. of Scientific and Industrial Research, New Zealand.

Stress corrosion tests on austenitic stainless steels were conducted in geothermal steam contaminated with chlorides, hydrogen sulphide, carbon dioxide etc. under the following steam conditions: a) Superheated air-free steam at 150 C; b) Steam superheated and aerated at 150 C.

Stress corrosion cracking occurred readily in the aerated superheated steam, but did not occur at all in the air-free superheated steam.

These test results provide experimental confirmation of Hoar and Hine's theory that the cathodic depolarizing action of dissolved oxygen is essential to the stress corrosion mechanism.

For comparison purposes, corrosion rate data and stress corrosion data on other alloys in the steam are given.

Some Practical Uses of Sodium Nitrite as an Inhibitor of Ferrous Corrosion by T. P. Hoar, Cambridge University.

Researches on sodium nitrite as an inhibitor of ferrous corrosion and some practical developments are described. Mechanism of the inhibition is discussed and practical advantages and limitations are pointed out.

Staining of Copper and Brass by Einar Mattsson, AB Svenska Metallverken, Vasteras, Sweden.

The copper alloys are known for their fine lustre and high resistance to corrosion but they tarnish, nevertheless, under certain circumstances. A surface oxidation of the metals normally occurs under the influence of the atmosphere. At elevated temperatures this process may result in colored so-called tempering films. The presence of hydrogen sulfide in the atmosphere may accelerate the reaction so that tarnishing occurs even at room temperature.

When copper alloys are exposed to an outside atmosphere containing sulfur dioxide, such as exists in cities and industrial areas, a black film will soon form on the surface. After some years, however, the film changes to a pleasing green patina.

Ugly dark stains, "water stains," are formed when copper-base material is left in contact with stationary water for a lengthy period. Such water damage may be caused, for example, by rain or condensed moisture in transit or in storage. A similar staining is caused by hygroscopic surface impurities. Typical examples are chlorides deriving from tap water that has evaporated on the metal surface, solder residues, hand perspiration, sulfuric acid and dust.

Copper alloys can be protected from corrosion by means of, for example, passivating inhibitors, slushing compounds, lacquers or packaging that provides a seal against water vapor.

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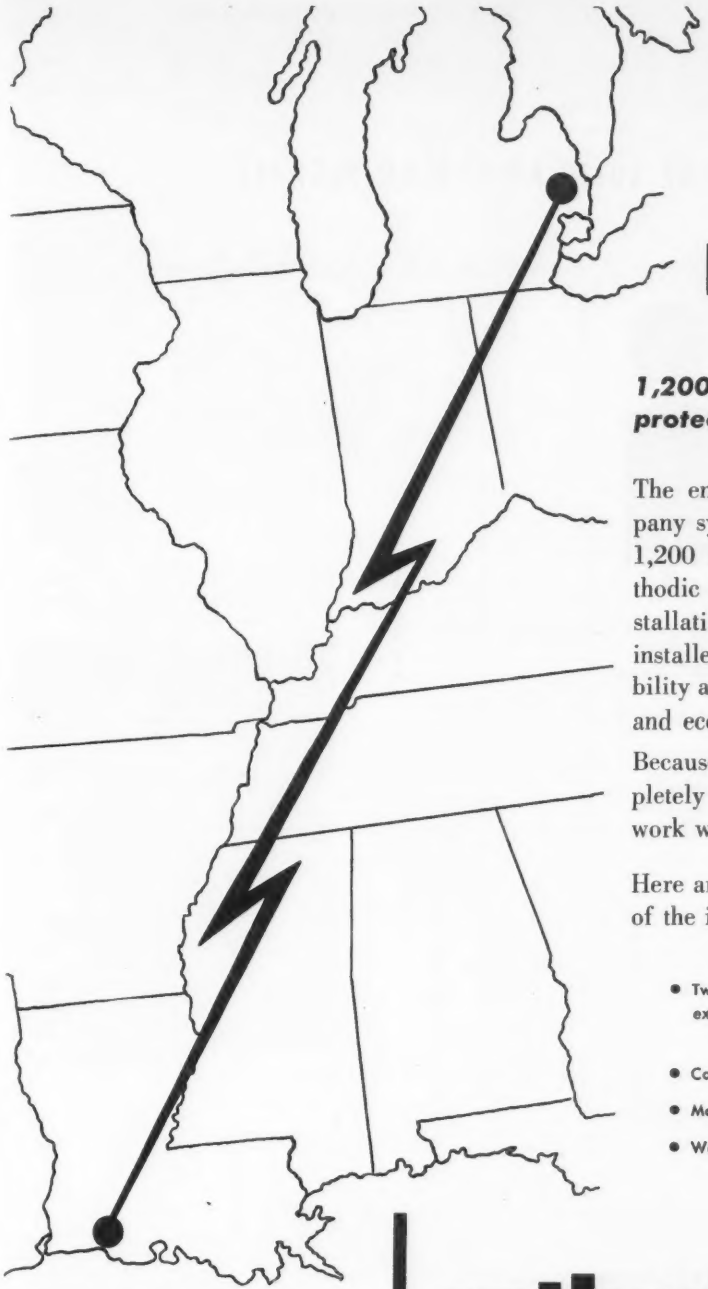
The 10-Year Index to CORROSION lists 1056 authors.



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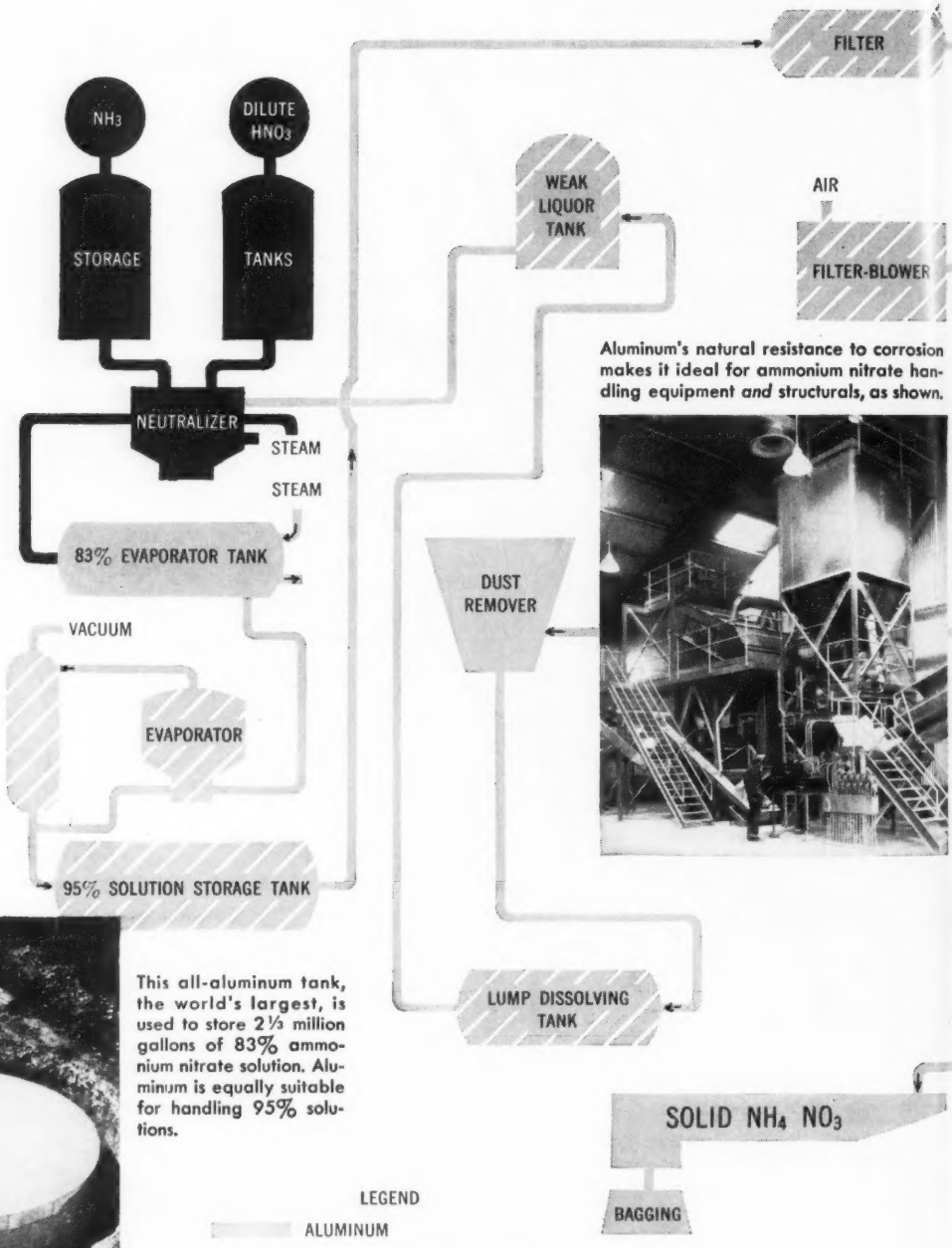
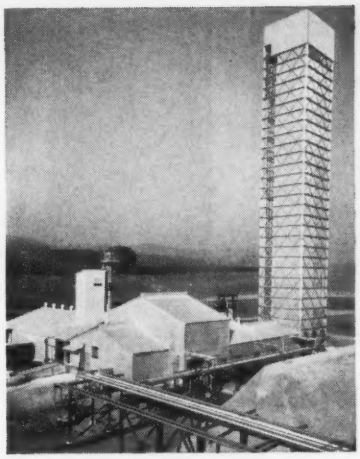
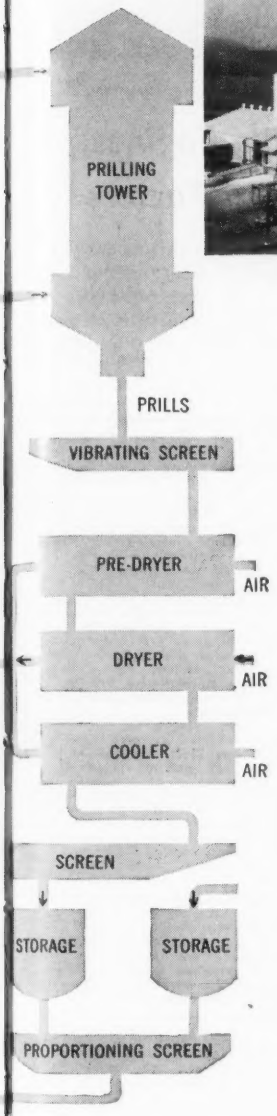


Aluminum's natural resistance to corrosion makes it ideal for ammonium nitrate handling equipment *and* structurals, as shown.

This all-aluminum tank, the world's largest, is used to store 2⅓ million gallons of 83% ammonium nitrate solution. Aluminum is equally suitable for handling 95% solutions.



This all-aluminum ammonium nitrate prilling tower is the tallest all-aluminum structure in the world—200 ft tall and 30 ft square. Frame, walls, piping, fittings, connections and fasteners all are aluminum to provide service uninterrupted by corrosion.



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Inhibitor Papers Cover Automobile Engines, Light Alloy Couples, Non-Chemical Factors

Four papers have been scheduled during the Chemical Inhibitor Symposium to be given during the 13th Annual NACE Conference at St. Louis. Papers on inhibitor problems associated with engine cooling systems, non-chemical air conditioning cooling water considerations, evaluation and on galvanic corrosion of magnesium-aluminum couples are included.

Abstracts of three of the papers are given below:

An Evaluation of Inhibitors for Corrosion Prevention in an Engine Cooling System, by Leonard C. Rowe, General Motors Corp.

The variety of coolants used in multi-metal engine cooling systems is a challenge to corrosion inhibition. Diverse characteristics of the systems are related to laboratory test methods used to investigate inhibition.

In a rotating specimen type of test effectiveness of inhibitors, including sodium borate, sodium nitrite, sodium benzoate, potassium dichromate, soluble oil and sodium mercaptobenzothiazole, is compared. Media include ethylene glycol-water mixtures and tap water with and without added corrosive constituents. Metals investigated are steel, copper, brass, aluminum, cast iron and solder. Results are recorded on rate, microscopic examination, pit depth and others. One year static room temperature tests on 13 galvanic couple combinations for each inhibitor are included.

Based on results obtained by conventional corrosion tests final examination of a combination of factors is made in a laboratory model which simulates an engine cooling system, indicating effectiveness in a system with either a copper-brass or aluminum radiator.

Investigation of Inorganic Inhibitors for Minimizing Galvanic Corrosion of Magnesium and Aluminum Couples by Sara J. Ketcham and Walter Beck, Naval Air Experiment Station, Philadelphia.

A fundamental study of some inhibitors found to be effective in reducing galvanic corrosion between magnesium alloy A231B and aluminum alloy 2024-T3 in saline solutions has been conducted. Object was to determine mechanism of protection afforded by inhibitors $Mg(VO_3)_2$, $BaK_2(CrO_4)_2$ and CaS singly and in combination. Effect on polarization characteristics of the metals was determined with electrodes isolated in separate compartments, bridging accomplished with agar-salt bridges. In this group of tests,

(Continued on Page 112)

BIOGRAPHIES

WALTER BECK—Now with Naval Air Material Center, U. S. Naval Base, Philadelphia, he formerly was assistant professor of metallurgy, Division of Corrosion Research at Lehigh University. Dr. Beck was educated in various European universities. He has been a member of NACE since 1948.

SARA J. KETCHAM—Metallurgist in the Surface Treatment and Corrosion Section of the Aeronautical Materials Laboratory, Naval Air Material Center, Philadelphia, she is occupied with research and development work in corrosion and protective coatings of aircraft. A graduate of Bryn Mawr College, she was employed in the Metallurgical Division of the Industrial Test Laboratory, Philadelphia Naval Shipyard.

LEONARD C. ROWE—Senior Research Chemist, Chemistry Dept., Research Staff, General Motors Corp. He holds a BS (1943) and MS (1947) from Michigan State University. He is active in corrosion activities for GMC and presently is chairman of its corrosion committee. He is a member of ACS and of NACE Unit Committees T-3A and T-4D; member of NACE Detroit executive committee and correspondent for the Transportation Industry for CORROSION

SIDNEY SUSSMAN—Chief Chemist, Water Service Laboratories, New York City. He has a BS, Polytechnic Institute of Brooklyn and a PhD, MIT. He formerly has worked for the DuPont Company, Permutit Co. and Liquid Conditioning Corp. His principal work is on corrosion control in water systems. He is a member of numerous engineering organizations, including NACE.

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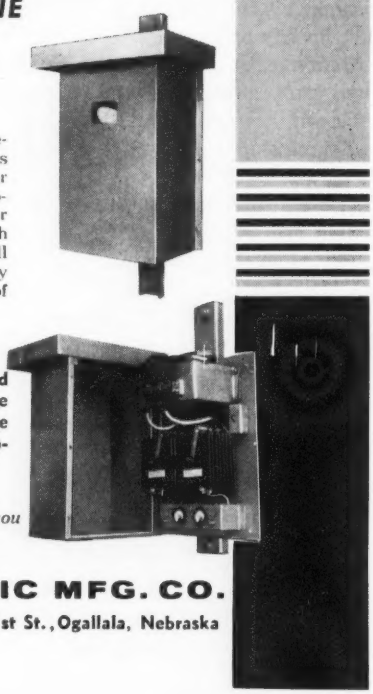

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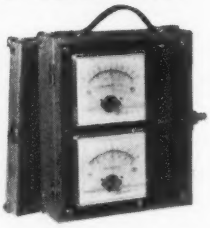

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Two-Paper Corrosion Principles Symposium Covers Intergranular Corrosion and Pitting

A two-paper Corrosion Principles Symposium has been scheduled for the 13th Annual NACE Conference at St. Louis.

Abstracts of the papers follow:

Intergranular Corrosion of Stainless Steel by W. B. DeLong, E. I. duPont de Nemours & Co., Inc., Wilmington, Del.

Intergranular corrosion of stainless steel is an unusual type of attack essentially limited to grain boundaries which leads to grain encirclement and loss (sugaring) of whole grains. It is associated with carbide precipitation in the same areas.

In this paper this type of corrosion will be described and character and origin of the precipitation discussed. Consideration will be given to the nature of aqueous media causing this type of attack both in the laboratory and in service. Practical means of avoiding it will be presented.

Pitting Corrosion by Hugh P. Godard and P. M. Aziz, Aluminium Laboratories, Ltd., Kingston, Ont.

Pitting, a highly localized form of corrosion, may lead to perforation with attendant costly consequences despite the fact an almost infinitely small percentage of the area of metal exposed to attack has been affected. (For example, a pit in a 55-gallon drum may be only 0.00005 percent of the internal area of the drum.)

Pitting occurs on film-protected metals such as aluminum, copper, stainless steel and zinc under environmental conditions where the surface films is almost, but not quite entirely protective. Under these conditions the overall corrosion rate is virtually zero, although the penetration rate of a pit may be as high as 5000 mpy. Pitting may be caused by local differences in the environment such as differential aeration, concentration, velocity or temperature or may be the result of local difference in the nature of the metal surface.

Pitting develops through three distinct stages, all of which have an electrochemical mechanism, and each of which is dependent on the other two: a) initiation; b) propagation; c) termination or stifling (this may or may not occur.)

Mechanism of the three stages is discussed and information presented on the enfluence of environmental variables such as pH, composition, velocity and temperature. Methods of statistical treatment of pitting data are illustrated. References to pertinent literature are included.

BIOGRAPHIES

P. M. AZIZ—On the staff of Aluminium Laboratories, Ltd., Kingston, Ont. since 1949, his principal technical activity is basic research on corrosion mechanisms of aluminum, on which he has published several papers. He has MA and PhD degrees from University of Toronto. In 1954 he received the Young Author award for the best paper published in CORROSION that year by an author under 35 years of age.

W. B. DeLONG—He is Research Manager, Materials of Construction Section, Engineering Department, Experimental Station, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del. He was co-chairman of the Chemical Industry Symposium for the 1954 NACE Conference at Kansas City.

HUGH P. GODARD—Long active in NACE affairs nationally and as a member of Canadian Region Dr. Godard has published many papers on corrosion fundamentals both in CORROSION and elsewhere. His principal interest is in corrosion processes related to aluminium as a consequence of his connection with Aluminium Laboratories, Ltd., Kingston, Ont. He has a PhD in industrial and cellulose chemistry from McGill University.

St. Louis Program Data In Earlier Issues Listed

Information on the program at the 13th Annual NACE Conference and Exhibition have been published in the January issue of CORROSION as follows:

Soil Box Demonstration Scheduled for Pipeliners, Page 105.

List of Exhibitors, Page 105.

Women's Program, Page 106.

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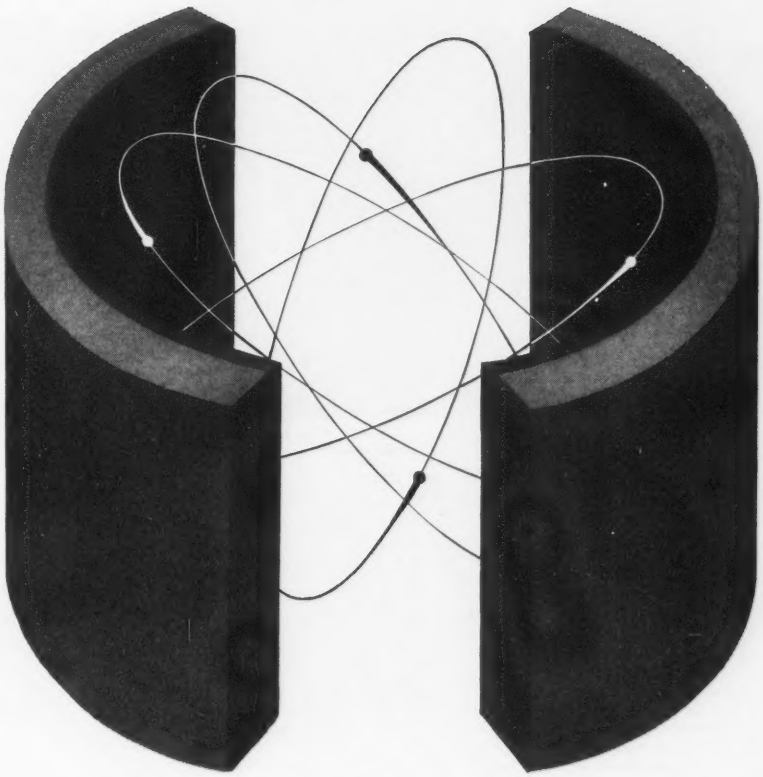

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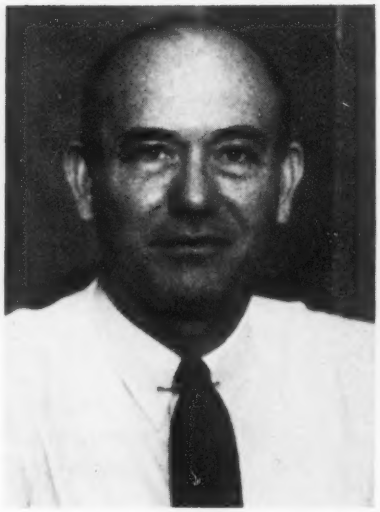
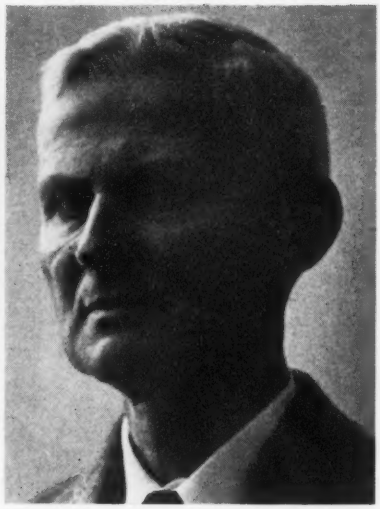


Walter F. Rogers



Carl Wagner

NACE 1957 Award recipients are Walter F. Rogers, Chief Chemist of the Houston Division Laboratory, Houston Production Division, Gulf Oil Corporation, Houston and Carl Wagner, Professor of Metallurgy, Massachusetts Institute of Technology. Mr. Rogers, 1953 president of the National Association of Corrosion Engineers, holds membership No. 2 in the association. With 27 years of experience in corrosion control, Mr. Rogers, besides functioning as an officer of the association has found time to be general chairman of the 1952 conference, chairman of Technical Practices Committee 1, chairman of the NACE awards committee in 1948 and contribute technical material for publication in CORROSION. He has served also on numerous other NACE committees. He is a graduate of the University of Pittsburgh, holding degrees in chemical engineering awarded in 1926 and 1934. His first job with Gulf was at Port Arthur, Texas in 1926. He is a native of Texas.

Dr. Wagner, a native of Liepzig, Germany attended universities of Munich and Liepzig from 1920 to 1924 and received a PhD in physical chemistry from the latter school in 1924. He successively became an assistant, University of Munich, 1924-27; research fellow at the University of Berlin, 1927-28; assistant, University of Jena, 1928-33; visiting professor, University of Hamburg, 1933-34; associate professor of physical chemistry, Darmstadt Institute of Technology, 1934-40; professor of physical chemistry, Darmstadt, 1940-45; scientific advisor, Ordnance Research and Development Division Suboffice (Rocket), Fort Bliss, Texas, 1945-49; visiting professor, department of Metallurgy, Massachusetts Institute of Technology, 1950-55 and was named professor of metallurgy at MIT in 1955.

Oil Chemist and MIT Professor To Be Honored

Walter F. Rogers, Chief Chemist Houston Production Division Chemical Laboratory, Gulf Oil Co., Houston and Carl Wagner, Professor of Metallurgy at Massachusetts Institute of Technology have been selected to receive the National Association of Corrosion Engineers' 1957 Awards. Mr. Rogers, 1953 past president of NACE and long active in association affairs, will receive the Speller Award for achievement in corrosion engineering and Prof. Wagner, known for his contributions to knowledge of physical chemistry, will receive the Whitney award for achievement in corrosion science.

The awards, established by NACE in 1947 and named in honor of their first recipients Willis Rodney Whitney and Frank Newman Speller, since have been given to 18 engineers and scientists who have made significant contributions to the world's knowledge of corrosion control.

Presentation of the awards will be at the annual banquet Wednesday, March 13 at the Sheraton-Jefferson hotel.

Fourteen Exhibitors Added to St. Louis List; Only 8 Booths Remain Unsold in Auditorium

Fourteen more exhibitors have contracted for space at the exhibition to be held concurrently with the NACE 13th Annual Conference March 11-15, 1957 at Kiel Auditorium, St. Louis. These, added to the 91 listed in CORROSION's January issue have contracted for all but eight booths of those planned for the exhibition.

The fourteen are:

Barrett Division, Allied Chemical & Dye Corp.
Automotive Rubber Company, Inc.
Chicago Metallizing Co.
Cosasco Division, Perfect Circle Corp.
F. Henry & Sons, Ltd.
Kraloy Plastic Pipe Co., Inc.
Labline, Inc.
Nooter Corp.
Owens-Corning Fiberglas Corp.
Protecto Wrap Company
Republic Steel Corp.
Joseph T. Ryerson & Son, Inc.
Tresco, Inc.
The Zopff Company.

Corrosion Programs Listed In Cebelcor Publication

A 7-page mimeographed list in French of meetings including matters pertaining to corrosion has been published by Centre Belge D'Etude de la Corrosion, 21 Rue Des Drapiers, Brussels, Belgium. Included are many of the important meetings all over the world known to have corrosion interest.

Corrosion Resistant Cast Alloy Designations Issued

A revised list of standard designations and chemical composition ranges for heat and corrosion resistant cast alloys has been issued by the Alloy Casting Institute, Mineola, N. Y. Copies of the chart are available on request.

Inhibitor Papers—

(Continued From Page 108)

polarization potentials, recovery potentials and corrosion currents were measured, the latter by means of a zero resistance ammeter. Additional tests were made with the electrodes in the same beaker, corrosion currents and rates being determined under these conditions.

Correlation of results from potential, corrosion current and corrosion rate data indicates that $Mg(VO_3)_2$ and $BaK_2(CrO_4)_2$ polarize aluminum strongly in the anodic direction, thereby reducing galvanic current and weight loss of magnesium. CaS is the only inhibitor that appears to polarize magnesium. A combination of these three inhibitors, therefore, results in a considerable reduction in the galvanic attack in a magnesium-aluminum couple in 0.1 N NaCl.

Non-Chemical Factors Effecting Inhibitor Selection and Performance in Air Conditioning Cooling Waters, by Sidney Sussman, Water Service Laboratories, Inc., New York.

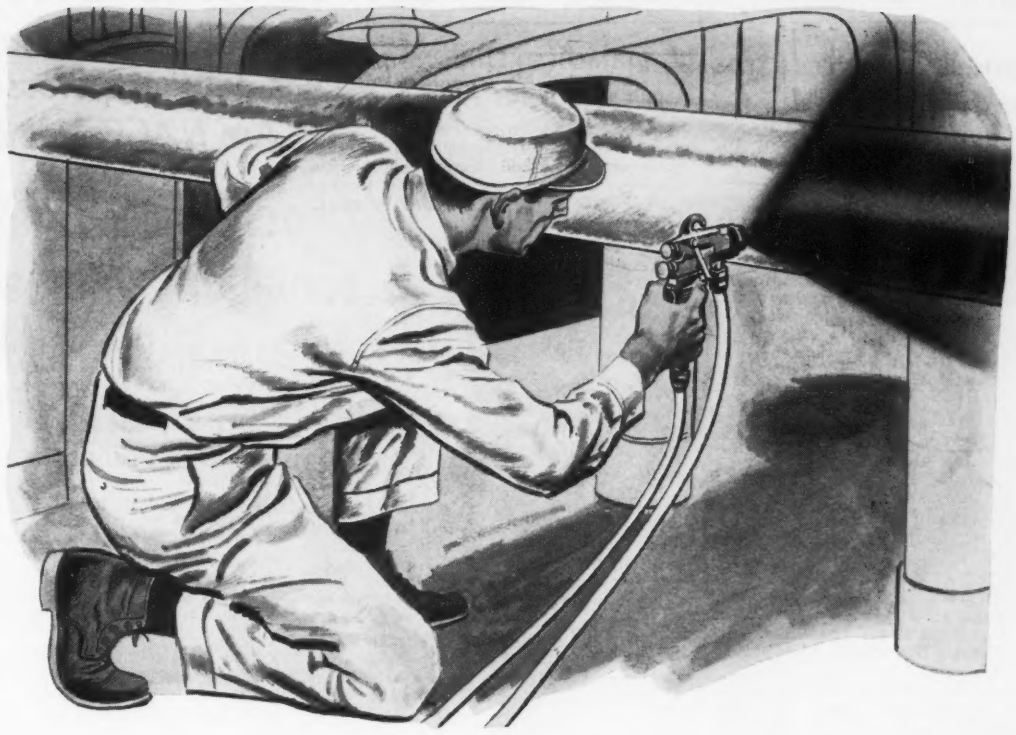
Effectiveness of corrosion control by chemical inhibitors in non-industrial air conditioning cooling water systems is subject to non-chemical factors to a degree not normally encountered in large industrial cooling systems.

Choice of an inhibitor or negation of an otherwise satisfactory corrosion control program, and an increase in safety hazards may result from selection of untrained personnel for equipment operation and maintenance. Inhibitor selection also may be restricted by legal requirements pertaining to cross-connections, water conservation or waste disposal.

Equipment location, rarely considered from the viewpoint of maintenance and corrosion control, frequently is a factor when choosing an inhibitor. Attempts to keep equipment and operating costs low frequently have secondary effects on corrosion control.

San Diego Section Elects New Officers for 1957

The 1957 section officers of San Diego Section have been announced as follows: Dan Nordstrom, The Gates Rubber Company, chairman; L. L. Flor, vice-chairman, and Kenneth R. Christy, secretary-treasurer, Federal Housing Administration. The officers were installed and took office January 23.



wash primers improve performance of cold coatings

On metal surfaces exposed to a corrosive atmosphere, wash primers improve the performance of cold coatings based on coal tar systems. Such primers made with Shawinigan Resins' FORMVAR, polyvinyl formal, or BUTVAR, polyvinyl butyral, not only provide excellent corrosion resistance . . . they also provide superior anchorage for the cold coating.

The use of a wash primer based on polyvinyl butyral is strongly recommended when metal pipe or metal structures are coated under conditions of high humidity, high atmospheric temperature and condensation. Anti-corrosive wash primers have a long history of success under such conditions. Only a 0.3 to 0.8 mil thick film is required to provide a tough, protective coating. Wash primers apply easier, adhere better, and dry faster than conventional materials. Formulation of a primer with FORMVAR or BUTVAR is easy in your regular ball or pebble mill.

Wash primers have extended the life of metals in many applications and have opened profitable new markets for paint manufacturers. For full technical information and suggested formulations, write Shawinigan Resins Corporation, Department 2702, Springfield 1, Massachusetts.

SALES OFFICES: ATLANTA CHICAGO LOS ANGELES
NEW YORK SAN FRANCISCO

FORMVAR® and BUTVAR® resins by

SHAWINIGAN RESINS

Night Credit Course on Corrosion Is Offered

Japanese Electrolysis Committeemen Meet

At a November 6 meeting of the Electrolysis Control Research Committee of Japan at Denkikyokai Bldg., Tokyo the following printed reports were issued:

Annual Report for 1955, including a list of active members.

Subcommittee Report on Reinforced Concrete Sleepers for Railroads.

Subcommittee Report on Utilization of the Sea as the Return Circuit for Railroad Electrical Systems.

Subcommittee Report on Chemical Corrosion of Lead Cable Sheaths.

Subcommittee Report on Cables With Protective Cevrings.

Subcommittee Report on Microbiological Corrosion of Underground Metallic Structures.

Subcommittee Report on Corrosion Statistics of Gas Pipe Lines for the Past Year.

Introduction of NACE Task Group T-4B-3 Report.

Subcommittee Report on Corrosion Control Installations for High Pressure Gas Pipelines Between Shitte and Hiranuma.

Subcommittee Report on Cathodic Protection With Zinc Anodes.

Subcommittee Report on Recommended Regulations for Drainage of Cathodic Protection Installations.

Report of the Activity of Tokai District Corrosion Control Committee.

Report of the Activity of Kansai Electrolysis Control Committee.

Paper on Estimate of Corrosion Losses to Underground Cables and Pipelines by Michio Tanaka.

Metals Congress Schedules Corrosion Panel Session

A panel session on Corrosion and Metal Protection will be given during the March 25-29 10th Western Metal Congress, Ambassador Hotel, Los Angeles as follows:

Cost of Corrosion and the Economics of Material Selection—Martin L. Michaud, Union Oil Co. of Cal., Los Angeles.

Importance of Inspection in Corrosion Control—E. H. Tandy, Chief Inspector, Standard Oil Company of California, El Segundo, Cal.

Metallic Coatings for the Protection of Steel—C. H. Sample, Manager, Electroplating, Section, Inco Research and Development Division, New York.

Non-Metallic Coatings in the Petroleum and Chemical Industry—Lester Morris, President, Coating and Fiberglass Research Co., Los Angeles.

Cathodic Protection, Principles and Application—L. L. Whiteneck, Pipeline Coating and Engineering Co., Los Angeles.

Appalachian Underground Course Set for June 5-7

A basic and an intermediate course on corrosion fundamentals will be features of the Second Annual Appalachian Underground Corrosion Short Course to be held June 5-7 at West Virginia University, Morgantown.

Also included on the program are:

Demonstrations in the field of procedures and techniques.

Coatings symposium on coal tar, asphalt, waxes, plastic and coal tar impregnated tapes.

Power and communication industries symposium, including six classes on cable corrosion.

Five classes on corrosion problems peculiar to the water industry covering steel, cast iron, asbestos-cement pipe; water pumps and internal coatings.

Mining industry corrosion problems will be covered by three instructors.

Special topic sessions will cover bacterial corrosion, well casing corrosion, electrolysis switches, design and application of cathodic protection and stray current interference with railway signal systems.

Papers will be published by the university and mailed to all registrants. Room and board will be available in university dormitories at reasonable prices.

Parthian Electroplaters Used Primary Cell

Parthian electroplaters living in the vicinity of Baghdad between 250 BC and 224 AD used a primary cell consisting of a copper container into which was inserted an iron electrode. The electrolyte could have been either acetic or citric acid, which was readily available to them.

This fact was developed after a primary cell was reconstructed according to the dimensions and design and metallurgical data of cells found among the ruins of Mesopotamia by the German archaeologist Wilhelm Koenig. Numerous remains of the cells, which were enclosed in earthenware jars after fabrication are on display at the Berlin museum. When Willard F. M. Gray, of General Electric's High Voltage Laboratory, Pittsfield, Mass, reconstructed one of the cells according to the ancient design, filled it with copper sulfate and connected them to a galvanometer —current flowed.

It is reasoned that the cells were used for electroplating.

(Abstracted from The Laboratory, Vol. 25, No. 4, Pages 112-113.)

Most Lecturers at Centenary Classes Are NACE Members

Three hours of academic credit will be awarded for a night school course titled "Introduction to Corrosion and Its Control" to be held at Centenary College, Shreveport during the current semester. Classes meet from 7 to 10 pm Thursday at the college's science building.

The course, designed primarily for persons employed by industries concerned with transportation of petroleum products, will cover fundamental theories of atomic structure, electrochemical behavior of matter, application of the Nernst equation, nature and mechanism of corrosion, principles of inhibitors and economics.

John B. Entrikin, head of Centenary's Department of Chemistry will be coordinator and open the January 31 session with a discussion on "Corrosion—What It Is and Its Importance." Guest lecturers will give some of the remainder of the classes. Final examination will be given May 16.

Schedule of classes and Instructors:

Electrochemistry of Corrosion, Feb. 7, 14, 21 and 28—Donal Emerich, associate professor of chemistry, Centenary.

Mechanisms of the Electrolytic Cell, March 7, 14, 21 and 28—Edward C. Greco, United Gas Corp.

Edward H. Sullivan, United Gas Pipe Line Corp. and Horace V. Beezley, United Gas Pipe Line Corp. will give one lecture each on "Prevention of the Corrosion Cell" April 4 and 11 respectively.

Practical Application of Theories Learned, April 18, 25; May 2, 9—M. J. Olive, Arkansas Fuel Oil Corp.

All but the first two lecturers are NACE members.

Further information on the course can be obtained from Edgar E. Burks, Director of Evening Div., Centenary College, Shreveport, La.

Pores in Electroplated Coatings Can Be Located

Size and position of pores in electroplated coatings can be determined by a new testing method developed at the National Bureau of Standards. The method involves exposure of a plated specimen to a photographic film and transmission of x-radiation through the basis metal side.

The work, carried out by F. Ogburn of the bureau staff and Margaret Hilkert of the American Electroplaters Society is reported in detail in "The Nature, Cause and Effect of Porosity in Electrodeposits, II. Radiographic Detection of Porosity in Electrodeposits," Annual Tech. Proc. American Electroplaters' Soc., Page 256, 1956.

CYANAMID

CORROSIONEERING with LAMINAC®
(Polyester Resins)

Reinforced Laminac needs no maintenance in over three years of highly corrosive service

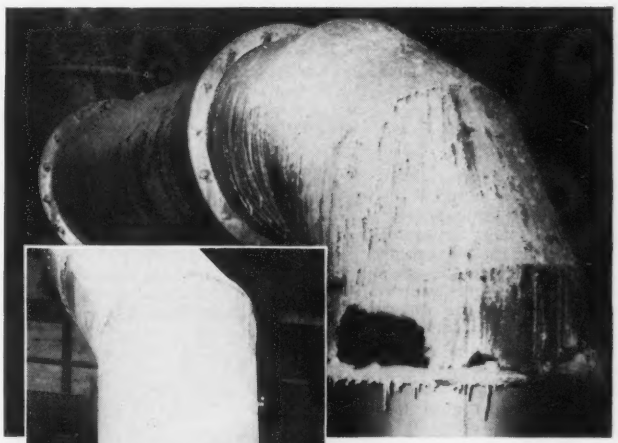
Here's dramatic evidence of the durability of glass-reinforced LAMINAC polyester resin in highly corrosive service!

In venting systems for alum evaporators and digesters at Cyanamid's Warners, N. J., plant, carbon steel breeches and stacks required frequent maintenance, failed after two or three years of service.

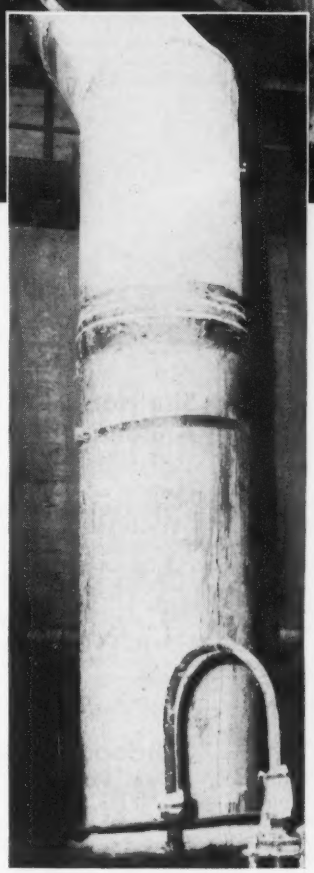
Breeches and stacks molded of reinforced LAMINAC resin by Carl N. Beetle Plastics Corporation were installed as replacements. In the 84′ stack installation, pictured at right, reinforced LAMINAC has served for more than three years without maintenance!

And long service life is only one advantage. Two 84′ stacks, supplied in six sections, were installed with telescope-type joints, wrapped and cemented at the site. Another 82′ stack, supplied in two sections, was installed with flange-type joints. Lighter by far than steel, the reinforced LAMINAC stacks were much easier to install, and cost considerably less in the long run.

If your problem is handling corrosive fluids or fumes, glass-reinforced LAMINAC can help you reduce maintenance, extend service life and reduce costs. Consult your Cyanamid representative on the "what-to-use" and "how-to-use-it" of LAMINAC polyester resins.



Carbon steel breeching, 3/16" thick, in this alum evaporator at Cyanamid's Warners plant failed after 3 years, was replaced with reinforced LAMINAC.



An 84′ stack of reinforced LAMINAC *resin, 1/4" thick, in even more severe alum digester service, has needed* no maintenance *in over three years.*

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MATERIALS FOR TOMORROW

BOOK NEWS

Tinplate Handbook. 44 pages, 6 x 9¾ inches, paper. By W. E. Hoare. October, 1956. Tin Research Institute, Inc., 492 West Sixth Ave., Columbus 1, Ohio. Price: Free.

Third revised edition describes tinplate and how it is made, gives figures on tinplate production and outlines two methods of tinning.

Units in use for measuring or quoting tin coating thickness are tabulated and described in Section IV. Section VI relates to packaging and Section VIII to testing. A glossary of tinplate terms gives English, French, German and Spanish equivalents.

Technical Report of the Activities of Commission IV of Association Belge Port l'Etude L'Essaie et l'Emploi des Materiaux. (In French). 44 pages plus Annex, 8½ x 10¾ inches, paper. March, 1956. Availability not indicated.

Report on the work for the year 1955. Chapters are included on studies related to paint for atmospheric service, marine exposures, and organization of studies devoted to metallic coatings and paints designed to protect against cold water; effects of aggressive atmospheres on corrosion and the resistance to corrosion or several kinds of iron.

Numerous data are tabulated on observations of exposed specimens. The annex includes formulae for anti-corrosive and anti-fouling paints and tabulated data on the characteristics of paint systems.

Stress Corrosion Cracking and Embrittlement. 202 pages, 6 x 9 inches, cloth. December 4, 1956. Edited by William D. Robertson. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y.; Chapman and Hall Ltd., London. Per Copy, $7.50.

Fourteen papers presented at a symposium arranged by the Corrosion Division of The Electrochemical Society at Boston, October, 1954. Titles of papers included are: The Phenomena and Mechanism of Stress Corrosion Cracking, Julius J. Harwood; The Structure of Grain Boundaries, Bruce Chalmers; Structural Factors Associated with the Stress Corrosion Cracking of Homogeneous Alloys, W. D. Robertson;

Stress Corrosion Cracking in Homogeneous Alloys, L. Graf; Metallurgical Aspects of Stress Corrosion Cracking in Aluminum Alloys, E. C. W. Perryman; Mechanism of Stress Corrosion Cracking Observed in a Magnesium Alloy, D. K. Priest; Role of Boundary Adsorption in Stress Corrosion Cracking, Rudolph Speiser, J. W. Spretnak;

Stress Corrosion Cracking of Austenitic Stainless Steels in Aqueous Chloride Solutions, T. P. Hoar, J. G. Hines; Phenomena of Stress Corrosion Cracking in Austenitic Stainless Steels, C. Edeleanu; Stress Corrosion Cracking of Mild Steels, R. N. Parkins; On the Mechanism of Chemical Cracking, U. R. Evans; Hydrogen in Iron and Its Alloys, W. R. Heller; Ductility of Steel with Varying Concentrations of Hydrogen, Taiji Toh, William M. Baldwin, Jr.; Laboratory Techniques for the Investigation of Stress Corrosion Cracking, H. R. Copson.

ASTM Standards on Zinc-Coated Iron and Steel Products. 134 pages, 6 x 9 inches, paper. September, 1956. American Society for Testing Materials, 1961 Race St., Philadelphia 3, Pa. Per Copy $2.25.

The volume includes 21 specifications, three recommended practices and five methods of tests related to zinc coatings on ferrous metals. Sponsored by Committee A-5 on Corrosion of Iron and Steel, the compilation includes all specifications coming under jurisdiction of the committee as well as selected specifications written by Committee A-1 on Steel, A-2 on Wrought Iron, B-1 on Wires for Electrical Conductors and B-2 on Non-Ferrous Metals and Alloys.

Materials covered include zinc-coated sheets, hardware, wire, strands, fencing, and pipe as well as Terne-alloy coated sheets.

Electrochemistry-Principles and Applications. By E. C. Potter. 418 pages. 6 x 9⅝ inches, cloth. January 15, 1957. The Macmillan Company, 60 Fifth Ave., New York 11, N. Y. Cleaver-Hume Press Ltd., 31 Wright's Lane, Kensington, London W. 8. Per Copy $10.

A text intended to acquaint the technical student and the specialist electrochemist with some of the theoretical and practical aspects of electrochemical reactions. The author considers the laws of electrolysis, electrolytic conductance and transport and ionic activity; ionic equilibria, reversible and irreversible processes; reference electrodes and cells;

Electric double layer and electrokinetic phenomena, electrochemical measurements, theoretical and practical aspects of metallic corrosion; general principles of technical electrolytic processes, cathodic and anodic processes and electrochemistry as a source of energy in primary and secondary and fuel cells.

There is an alphabetical subject index and bibliography.

Sea Horse Institute Announces Five Sessions

Scheduled meetings of the Sea Horse Institute and special engineering groups at the Harbor Island test station of the International Nickel Co., Inc., have been announced as follows:

April 24-26—Petroleum engineers.

May 8-10—Marine and power engineers.

May 27-29—Chemical engineers.

June 1-14—Sea Horse Institute and Marine Borer Conference.

September 11-13—Small boat builders.

Outdoor Storage in Agenda At Materials Handling Meet

Two of the four topics on a session devoted to outdoor storage of materials are significant to corrosion control workers attending the 7th National Materials Handling Conference, Philadelphia, April 29-May 3. The subjects of interest, to be discussed during the morning of May 1 are: Why Build a Warehouse When You Can Store Outside? and What We Need to Know About Outdoor Protection.

American Materials Handling Society is sponsor.

Magnetic Particle Testing Photographs Published

Forty-seven reference photographs recently published by the American Society for Testing Materials, 1961 Race St., Philadelphia, Pa. make possible ready identification of discontinuities in iron and steel castings. The photographs cover linear discontinuities, shrinkage, inclusions, internal chills and unfused chaplets, porosity, weld discontinuities, false indications and magnetic anomalies. The photographs were made available by the Steel Founders' Society of America. They cost $2.50.

Hot Dip Galvanizers to Stress Quality Control

American Hot Dip Galvanizers Association, Inc., has organized a Quality Control Committee headed by Frank Soles, Works Manager, Delta-Star Electric Div., H. K. Porter Co., Inc., Pittsburgh and Frank M. Miller, Contracting Engineer, Lehigh Structural Steel Co., Allentown, Pa., co-chairmen. Aim is to stress importance of coating that will give long service life.

Cost Engineers' Meeting

Norman Bach, Monsanto Chemical Co., Texas City, Texas president of the American Association of Cost Engineers will be among those attending the association's board of directors winter meeting in New York City February 14-17. National meeting of the group is scheduled June 26-29 at University of New Hampshire, Durham.

Lapel Pins

Approx. Size

Approximately 7/16 inches high, gold, inlaid with bright red enamel background to "NACE" and deep blue enamel background to words "CORROSION CONTROL." Ruby center.

•

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$10

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A. B. Campbell, Executive Secretary

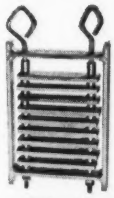
NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg., Houston 2, Texas

Here's a crystal ball

that accurately predicts metal performance at high temperatures:

Inco's in-plant test rack program



Do you know that Inco sets up a test rack containing a large selection of alloys in critical hot spots in many types of operations: — one rack or more . . . whatever it takes to find out which alloy stands up best under a host of varying high temperature conditions.

What's more, Inco's High Temperature Engineering Service tabulates the data . . . analyzes it in a report like the one above: complete . . . accurate . . . unbiased.

Perhaps the answer to your high temperature problem has already been found . . . if not, we will be glad to arrange for a rack test. All you have to do to get the crystal ball rolling is to fill out the coupon below. Do it now.

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67 Wall Street, New York 5, N. Y.

Please send me the High Temperature Work Sheet so that I may outline my problem to you.

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Equipment Services NEW PRODUCTS Materials Literature

High Efficiency Filters for gas, oil, water and smoke can be made from microfibers produced by a process patented by American Viscose Corp., 1617 Pennsylvania Ave., Philadelphia 3, Pa. The fibers, which have a permanent electric charge, irregular length and diameters from 0.5 to 10 microns, can be made of vinyl, acrylic resins, Nylon and polyesters as well as asphalt.

•

Kaiser Aluminum & Chemical Corp. has purchased the wire and cable business of United States Rubber Co.

•

Scotchrap Vinyl tape application methods are shown in a 20-minute color motion picture "All Holes Barred," available from Minnesota Mining & Mfg. Co., Dept. D7-2, St. Paul, Minn. It is designed for free showing to workmen using vinyl pipe insulating tape.

•

Carbides containing titanium, tantalum and tungsten combinations can be brazed under unusual conditions using a special flux developed by General Electric Company's Metallurgical Products Dept., Detroit, Mich.

•

Industrial Plastic Fabricators, Inc., Norwood, Mass. is making a 40-inch PVC centrifugal blower rated at 15,000 cfm.

•

Heavy Copper-Plated high-strength steel communications wire is being made now at the Niles, Mich. plant of National-Standard Co. It is available in two grades, with 30 and 40 percent conductivity in both high and extra high strength classes. It is produced in standard sizes from No. 1 to No. 12 AWG.

•

20-Bottle Rotator Oscillators for running 20 simultaneous tests on corrosion coupons or for other laboratory purposes are available from Labline, Inc., 3070-82 W. Grand Ave., Chicago 22, Ill. The oscillators were developed in connection with the Pure Oil Co. Research Laboratories and are described in Bulletin 5300-1.

•

An Air Force nuclear reactor at Bell Telephone Laboratory's Whippany, N. J. location will be used by the company in tests of properties of solids used in military electronic systems.

•

Thermopiles for conversion of infra-red energy into electrical energy suitable for amplification and measurement are described in a 12-page brochure available from Jarrell-Ash Co., 26 Farwell St., Newtonville 60, Mass.

•

Aircraft Door frame structures are inspected at Pan-American Airways, San Francisco to locate promptly cracks or corrosion and recheck welded repairs. A portable x-ray unit made by Holger-Andreasen, Inc., 703 Market St., San Francisco, Cal. is used. Failure of areas adjacent to windows and doors was ascribed as the reason for the disintegration in flight of British pressurized jet transport planes with the loss of several score lives.

G. S. Plastics Co., 15583 Brookpark Rd., Cleveland 11, Ohio has been organized for custom coating with plastics by William A. Munkacsy, formerly president of Munray Products.

•

Halocarbon Grease Series 25-10, a chlorofluorocarbon material manufactured by Halocarbon Products Corp., Hackensack, N. J. is designed for use in lubrication of areas where its inertness to corrosives is important.

•

DeVilbiss Spray Finishing schools will be conducted at the company's Toledo School beginning on the following dates: February 4, March 11, April 1, May 6 and June 3.

•

Solvay Products, a book giving comprehensive information on chemical products by Solvay Process Division, Allied Chemical & Dye Corp. can be obtained by writing to Dept. PB, at the company's 61 Broadway, New York 6, N. Y. offices.

•

Ekki, or iron wood, among the hardest natural woods of the world and said to have the highest resistance to abrasion is recommended as an engineering material for corrosive and other obvious services by F. Henry & Sons, Ltd., 73-29 174th St., Flushing 66, N. Y. Literature reports show the timbers have been used successfully abroad in salt water as piling where service of over 18 years without attack by teredos is reported. Autracon, an acid resisting wood, is highly resistant to rot, termites and abrasion also is available from this firm, which imports both woods from Africa. Literature is available on request.

•

Bare aluminum 8-inch pipe was installed for 20,000 feet by Lavaca Pipe Line Company to bring natural gas to Aluminum Company of America's Point Comfort, Texas plant. The Schedule 40 pipe is insulated at flanged joints, was welded by the argon shielded tungsten arc method and is designed to operate at pressures slightly under 500 psi. Tested at 800 psi, it has a calculated bursting pressure of 1500 psi.

•

Cathodic Protection Rectifiers, an 8-page two-color brochure issued by Good-All Electric Mfg. Co., Ogallala, Neb. describes and illustrates the company's lines of selenium rectifiers. Copies are available on request.

•

Butvar, polyvinyl butyral and Formvar, polyvinyl formal wash primers designed for service where resistance to corrosion is important are described in a 12-page booklet available from Dept. EF, Shawinigan Resins Corp., Springfield 1, Mass. Properties of the two materials are discussed and sections on the properties of the formulated primer and suggested end-uses are covered.

•

Pacemaker, a high powered mobile drill designed by Mobile Drilling, Inc., 960 North Pennsylvania St., Indianapolis, Ind. can generate up to 5 tons of push or pull ram force, handles 6-foot sectional augers from 3 to 24 inches in diameter and drives a full 6-foot stroke. It bores 150 feet in unconsolidated materials and up to 600 feet with N rod and 1000 feet with A rods. It features the exclusive Mobile Drill hollow stem auger which permits undisturbed soil sampling.

•

Spent Pickle Liquor can be regenerated by a process developed by Zahn & Co. West Berlin, Germany, exclusive rights to which have been obtained by Koppers Co., Inc. Operating on a continuous cycle, the process maintains the liquor at a consistent concentration and saves sulfuric acid.

•

Koncour electronic thickness testers operate with an accuracy of 90-95 percent accuracy, according to Koncour Co., Dept. K-8, 4800 South St. Louis Ave., Chicago 32, Ill. A multiple position switch permits setting for kind of plating to be tested.

•

Titanium produced in the United States during 1956 weighed 5,300 tons in finished mill shapes according to Titanium Metals Corp. of America, 233 Broadway, New York 7, N. Y. More than 11,000 tons of ingot metal was produced.

•

Alpha Plastics, Inc., Okner Parkway, Livingston, N. J. has completed a new plant exclusively devoted to producing polyvinyl chloride pipe and fittings.

•

Fairprene T-5594 ready-cured synthetic rubber lining material is offered in a package including adhesives and primers by DuPont's Fabrics Division. It is available only in two-ply, 50-inch widths ⅛ inch thick. Bonding with air-drying cement has proved satisfactory in field tests.

•

Hagan Chemicals and Controls, Inc., is the new firm name for Hagan Corporation effective January 1, 1957. Subsidiaries Calgon, Inc., Hall Laboratories, Inc. and Buromin Co. were merged into the parent company. Calgon and Hall will continue as divisions.

•

Mallory-Sharon Titanium Corp., Niles, Ohio will build a pilot plant to investigate refining titanium scrap, using a new electrolytic process said to yield extremely pure metallic titanium. Electrolytic metal with a Brinell hardness of 60 has been made in the laboratory.

•

American Lithium Institute, Inc. has been formed for the purpose of conducting research on lithium and its compounds.

•

Properties of Heteropolymolybdates, a 15-page bulletin covering properties, uses, classification, nomenclature and preparation of heteromolybdates and containing a section on the literature related to uses of these compounds has been republished by Climax Molybdenum Co., 500 Fifth Ave., New York 36, N. Y.

Paint protection against rapid corrosion **inside your pipelines!**

In-place coating with Humble's epoxy internal pipe coatings gives you proven protection against rapid corrosion in sour crude oil, salt water and natural gas lines. These durable coatings can be applied in a single application to pipelines in the ground. In addition to giving lasting resistance to sour crudes and brine, Humble epoxy internal pipe coatings give a smooth, glossy finish that cuts down paraffin deposition.

Humble internal pipe coatings are also available in vinyl and phenolic formulations.

For more information on Humble's complete line of protective coatings, see your nearest Humble wholesale plant in Texas and New Mexico, or write or phone:

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Technical Service
Sales Department
Humble Oil & Refining Company
P. O. Box 2180
Houston 1, Texas

MEN in the NEWS

Ted L. Canfield, formerly head of the Corrosion Engineering Department of consolidated Gas Utilities Corp. is now a corrosion engineer in the Tulsa office of Cathodic Protection Service.

•

Ralph B. Pass, for 2½ years a corrosion engineer with Southern Natural Gas Co. has been assigned to the New Orleans branch office of CPS while Leslie L. Dickson, formerly with Public Service Company of Colorado in its Gas Engineering Department is now in the firm's Houston office.

John W. Cosier has been named chief product engineer of The Pfaudler Co., Rochester, N. Y.

•

Conrad F. Nagel, Jr., vice-president of Aluminum Company of America, retired January 1 after 41 years' service with the company. He developed a process for feathered aluminum, a type used in explosives.

•

William H. Weed has been appointed manager, Engineering Dept., Mutual Chemical Division, Allied Chemical and Dye Corp.

•

John D. Hoffman has been named head of the new Dielectrics Section established at the National Bureau of Standards.

This Quantometer at Standard Magnesium means

POSITIVE QUALITY CONTROL

At the Tulsa plant of Standard Magnesium Corp., this Quantometer analyzes magnesium faster—and to a greater degree of accuracy (within .0001%) than any other method.

What does this mean? . . . First, because of its great accuracy, it assures consistent high quality. This means material to your exact specifications because a sample of every melt is analyzed before pouring.

Secondly, it gives a printed analysis in a matter of seconds from samples speedily delivered from the mill to the lab through pneumatic tube systems. Other metal analyzing methods rely on a time consuming, error-liable human analysis of results.

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Joseph Friedman has been elected president of Chromalloy Corp., White Plains, N. Y.

•

B. D. Thomas has been named director of Battelle Memorial Institute, Columbus, Ohio.

•

Thomas Dunsheath has been promoted to the position of technical director of the automatic control systems section of Cook Research Laboratories.

•

E. W. Fisher has been named manager of the Product Engineering Department of The Garlock Packing Co., Palmyra, N. Y.

•

Robert H. Brown has been named assistant director of Alcoa Research Laboratories and **Charles J. Walton** has been named chief of the chemical metallurgy division. Mr. Brown received the 1950 NACE Whitney Award and Mr. Walton has been a frequent contributor of technical material for publication in CORROSION.

•

Paul M. Brister has been appointed manager of the Engineering Design Section of the Babcock & Wilcox Company's Manufacturing Engineering Department. He will be at the company's Barberton, Ohio works.

•

Robert P. White has been vice-president in charge of the H. C. Price Company's Pipe Coating Division. He has been with Price 17 years and manager of the pipe coating division since 1951.

•

Harry A. Fedderson has been named technical director of Loven Chemical of California, Newhall, Cal.

•

Victor Mauck, until January 1956 chairman of the boards of the John Wood Company and Nicolet Industries, Inc. died December 6 at the age of 82. He had been associated with the John Wood Company for 65 years. He is credited with being the first to perfect continuous welding of tube steel in large diameters and heavy gauges. He was one of the founders of the American Welding Society.

•

Andrew J. Frank, a University of Illinois graduate has been assigned as research chemist to the Metallurgy Division at Denver Research Institute, University of Denver, Denver, Col.

•

James J. Callahan, senior metallurgical engineer for the Thermal Products Division, Alco Products, Inc. died December 26 at the age of 61. He has been associated with the company since 1917.

•

C. G. Duncombe is now affiliated with The Hinchman Corp. as a consulting engineer and has become a member of the firm's board of directors. The corporation is embarking on a program extending its activities into problems associated with atmospheric and stream pollution.

•

Philip J. Olmstead has been appointed chief engineer of Goulds Pumps, Inc. He is a member of ASME and NACE.

•

Leslie L. Seigle has been appointed manager of metallurgical research at the Corporate Research Laboratories of Sylvania Electric Products, Inc.

CORROSION ABSTRACTS

INDEX TO CORROSION ABSTRACTS

Vol. 13 February, 1957 No. 2

1. GENERAL
   1.2 Importance 121
2. TESTING
   2.3 Laboratory Methods and Tests 121
   2.6 Preparation and Cleaning of Specimens 122
3. CHARACTERISTIC CORROSION PHENOMENA
   3.1 General 122
   3.2 Forms 122
   3.4 Chemical Effects 122
   3.5 Physical and Mechanical Effects ... 123
   3.6 Electrochemical Effects 124
   3.7 Metallurgical Effects 124
   3.8 Miscellaneous Principles 125
4. CORROSIVE ENVIRONMENTS
   4.2 Atmospheric 126
   4.3 Chemicals, Inorganic 126
   4.5 Soil 127
   4.7 Molten Metals and Fused Compounds 127
5. PREVENTIVE MEASURES
   5.1 General 128
   5.2 Cathodic Protection 128
   5.3 Metallic Coatings 130
   5.4 Non-Metallic Coatings and Paints 130
   5.5 Oil and Grease Coatings 133
   5.6 Packaging 133
   5.9 Surface Treatment 133
6. MATERIALS OF CONSTRUCTION
   6.2 Ferrous Metals and Alloys 136
   6.3 Non-Ferrous Metals and Alloys—Heavy 138
   6.4 Non-Ferrous Metals and Alloys—Light 143

1. GENERAL

1.2 Importance

1.2.2, 1.7.3, 8.4.3

How to Sell Corrosion Control to Management. J. C. SPALDING, JR. Paper before Univ. Oklahoma, Corrosion Control Short Course, April 5-7, 1955. *World Oil*, **142**, No. 1, 170, 172, 175, 176 (1956) Jan.

How Sun Oil Co.'s corrosion engineers put their program across. Instead of trying to impress management with technical data, it was found that corrosion control can be sold through use of records, analyses and calculations that demonstrate positive monetary savings. Case history of use of inhibitors in oil wells is presented to illustrate this theory.—INCO. 11671

2. TESTING

2.3 Laboratory Methods, Tests

2.3.1, 2.2.3

Laboratory Tests for Predicting the Behaviour of Metals. C. E. HOMER. *J. Birmingham Met. Soc.*, **35**, No. 4, 304-321 (1955) Dec.

Testing behavior of metals in service with full scale trials or simulative tests; corrosion testing; cracking of steel under repeated stress; hot cracking in welding and casting; hot and cold working properties. Examples quoted are mainly low- and high-alloy steels, some reference is made to aluminum alloys.—BNF. 11932

2.3.2, 6.2.5, 3.2.2, 3.7.3

Methods of Testing Stainless Steels for Their Tendency to Intercrystalline Corrosion. (In Russian.) *Factory Laboratory, USSR* (Zavodskaia laboratoriia), **21**, No. 11, 1314-1345 (1955).

Zonal peculiarities resulting from welding. Corrosion media. Basic reasons for tendency to corrosion. Micro-structural peculiarities; distribution of ferrite and austenite grains. Graphs, micrographs, diagrams, tables. 68 references.—BTR. 11876

2.3.2, 2.4.2, 6.2.5

All-Glass Multiple-Test Apparatus for Corrosion Testing of Stainless Steels. J. V. ALGER, E. C. ROBERTS, R. P. LENT AND G. W. ANDERTON. *Bull. Am. Soc. Testing Materials*, No. 214, 57-60 (1956) May.

Describes construction and performance of an all-glass multiple-test apparatus for evaluating susceptibility to intergranular corrosion and corrosion resistance of stainless steels in boiling 65 percent nitric acid. Since corrosion products are removed by gravity flow as they are formed, apparatus gives results in good agreement with those obtained by testing material singly in flasks where enough acid is used to dilute corrosion products (Huey Test). Tables and graphs compare data obtained with multi-sample test and standard test on Types 304L, 309SCB, 347 and 308L. Diagram of apparatus.—INCO. 11923

2.3.4, 3.6.2

Methods of Studying the Corrosion of Metals at Contact Interfaces. (In Russian.) I. L. ROZENFELD AND I. K. MARSHAKOV. *Factory Lab., USSR* (Zavodskaia laboratoriia), **21**, No. 11, 1346-1353 (1955).

Peculiarities of corrosion along contacts of varying tightness between metal and porcelain, glass, bakelite or other metals. Relation of total corrosion losses, intensity of corrosion and area affected to the size of the interspace in acid electrolytes of varying strength. Graphs, diagrams. 9 references.—BTR. 11916

2.3.4, 5.8.1, 8.4.3

A Laboratory Method for the Evaluation of Oil Production Corrosion Inhibitors. DAVID B. BOIES. *Corrosion*, **12**, No. 8, 371t-375t (1956) Aug.

A test method used to screen and evaluate oil production corrosion inhibitors is described. Laboratory conditions are made to approximate field conditions as closely as possible with 20 ga mild steel (SAE 1010) as the test specimen. The effects on inhibitor performance of such variables as temperature, oil-brine ratio, aromatic content of oil blend and composition of gas phase are shown graphically. 11886

JANUARY "a" NUMBERS

Note: Addition of the affix "t" to the serial pagination of the Corrosion Abstract Section in the January, Pages 1a through 18a, was incorrect. These pages should have had the affix "a."

2.3.5, 4.5.3, 5.2.1

Installation for Studying the Anti-Corrosion Potential of Metal in Soil. (In Russian.) N. D. TOMASHOV AND IU. N. MIKHAILOVSKII. *Factory Lab., USSR* (Zavodskaia laboratoriia), **21**, No. 11, 1380-1382 (1955).

Circuit of installation for stabilization of electrode potential in soil during cathodic polarization. Change in cathodic current density with time during polarization of cast-iron electrode in soil. Effect of moisture of soil on corrosion rate. Circuit diagram, graph, table.—BTR. 11914

2.3.5, 5.2.1

Model Tests for Invesigating Cathodic Protection in Soil. T. MARKOVIC. *Werkstoffe u. Korrosion*, **6**, No. 12, 580-581 (1955) Dec.

To clarify corrosion processes of buried metals, corrosion tests were carried out under varying conditions of water-air content ratio by means of model cells; these cells consisted of two electrodes of different metals of the same size. Iron in contact with zinc was found almost completely protected under increased attack of the zinc as the base electrode if oxygen was eliminated. This means that the accession of oxygen to the electrode is hindered by saturation of the soil with water.—INCO. 11743

2.3.7

Abrasive Jet Method for Measuring Abrasion Resistance of Organic Coatings. A. G. ROBERTS, W. A. CROUSE AND R. S. PIZER. *Bull. Am. Soc. Testing Matls.*, No. 208, 36-41 (1955) Sept.

New method for measuring abrasion resistance of coatings utilizing jet of fine abrasive particles that abrades through coating to substrate. Flow rate, pressure, distance and angle controlled.—BL. 11812

2.3.7, 2.1.1, 3.5.8

1) The Statistical Interpretation of Fatigue Tests. 2) Application of Statistical Analysis to the Interpretation of the Results of Fatigue Tests. (In Italian.) F. GATTO. *Alluminio*, **24**, No. 6, 543-554, 555-560 (1955) Nov./Dec.

1) Reviews the various statistical methods for the interpretation of fatigue test results. 21 references. 2) Deals in greater detail with two methods proposed by the author (that of data rearrangement and that of local averages), using data for Ergal 65-type alloys (aluminum-8 zinc-2.6 magnesium-1.6 copper). See also Gatto's paper in the IUTAM Colloquium.) —BNF. 11816

2.3.2

The Effect of Varying the Experimental Factors Upon the Results of the Mylius Corrosion Test. (In Hungarian.) GABOR SZONYI. *Hungarian J. Metallurgy* (Kohaszati lapok), **10**, No. 10, 444-451 (1955) Oct.

Investigations for determining the

sources of error, limits of accuracy and recommended applications. Graphs, tables, micrographs, photographs, diagram. 13 references.—BTR. 11554

2.3.7, 3.5.3

Determination of Cavitation by Means of Brittle Coatings. (In Russian.) E. V. TRIFONOV AND V. I. DUMOV. *Energomashinostroenie*, No. 1, 25-26 (1955) October.

Composition and application technology for varnish coatings. Use in study of cavitation in centrifugal pumps. Causes of cavitation. Photographs, graphs. 4 references.—BTR. 11748

2.3.7, 6.6.6

Present Tendencies in the Evaluation of the Mechanical Strength of Refractory Products at High Temperature. (In Italian.) J. BARON. *Metallurgia Italiana*, **48**, No. 1, 10-14 (1956) Jan.

Investigation of the usefulness of sinking and creep tests for silicon dioxide and aluminosilicate refractories.—BNF. 11934

2.3.9

Quantitative Determination of the Wear of Machine Parts by Means of Radioactive Tracers. (In Russian.) YU. S. ZASLAVSKY AND G. I. SHOR. *Bull. Acad. Sci. URSS* (Izvest. Akad. Nauk SSSR), Technical Sciences Section, No. 4, 43-52 (1955).

A radioactivated steel shaft was rotated in contact with a slip ring immersed in oil. The oil was continuously pumped round a circuit which included heating and cooling coils and passed over counters. The counting rate due to radioactivated wear particles in the oil was carefully compared with the weight loss of the shaft. Agreement was $\sim \pm 5\%$. The apparatus was used to determine wear rates of piston rings as a function of speed, temperature of the lubricant and chemical nature of the lubricant. 15 references.—MA. 11829

2.3.9, 7.1, 6.3.6

The Use of Radioisotopes in Studying the Wear of Structural Constituents of Bronze. (In Russian.) V. E. VAINSHTEIN. *Bull. Acad. Sci., URSS* (Izvest. Akad. Nauk S.S.S.R.), Technical Sciences Section, No. 5, 114-118 (1955).

Apparatus and technique are described for studying wear in antifriction bearings. A bronze bearing containing tin 5, zinc 5, and lead 10% was made up, using radioactive tin, zinc and lead. Wear of the bearing was studied by causing the oil in a feed-lubrication system to pass over counters after lubricating the bearing. Concentration of individual metals in the oil was obtained by suitable choice of the isotopes used and suitable screening of the counters. Results were: i) In the period of running-in of the bearings, loss of lead (which is present in the alloy in free form) proceeds faster than loss of the solid solution of tin and zinc in copper. ii) The presence of dust in the lubricant reduces the initial wear of the bearing. iii) After the initial running-in period, the presence of dust in the lubricant increases the rate of wear of bronze and also of steel.—MA. 11813

2.6 Preparation and Cleaning of Specimens

2.6, 2.3.7

A Simple Graphical Method for Checking the Adequacy of Stress Corrosion Specimen Dimensions Against Stress Concentrations: A Technical Note. ROBERT H. HAY. *Corrosion*, **12**, No. 4, 171t-173t (1956) April.

The design problem created by the anomalous failure of thin stress corrosion sheet specimens at the loading pin holes is described. A simple theory taking into account stress concentrations due to holes and fillets is developed and is reduced to a convenient, easy-to-use graphical form which is explained by examples of its use. 11082

3. CHARACTERISTIC CORROSION PHENOMENA

3.1 General

3.1, 4.3.2

Causes of Corrosion. Part II. (In German.) H. GRUBITSCH. *Chem.-Ing.-Tech.*, **28**, No. 1, 9-24 (1956) Jan.

The corrosion processes of the system metal/solution is discussed, with special reference to the fundamentals and phenomena of the primary reactions of acid corrosion. A further concluding report will deal with the corrosion by neutral electrolyte solutions. Graphs, diagrams, table. 396 references.—BTR. 11620

3.1, 5.1, 2.3.1, 1.3

Corrosion of Metals. S. C. BRITTON. Reports on the Progress of Applied Chemistry, 1954 (Soc. Chem. Ind.), 1955, 105-116.

Experimental methods; high temperature, atmospheric, aqueous and underground corrosion; special corrosive agents and resistant materials; inhibitors; protective coatings; cathodic protection. 118 references.—BNF. 11708

3.2 Forms

3.2.2, 2.3.7

Pinholes in Thin Steel and Pinhole Detecting Apparatus. G. H. RENDEL. U. S. Steel Corp. *Iron Steel Engr.*, **32**, No. 11, 57-64; disc., 64 (1955) Nov.

Discusses the types and causes of perforations, need and functions of pinhole detectors and development of pinhole detecting equipment from earliest to most recent models.—INCO. 11794

3.2.2, 5.9.2

Proper Rinsing Practice Curbs Pinpoint Corrosion. L. J. BROWN, S. SPRING AND W. J. HENNESSEY. Pennsylvania Salt Mfg. Co. *Iron Age*, **176**, No. 22, 110-114 (1955) December 1.

Investigation of pinpoint corrosion, long a problem in the steel industry, shows that rust of this type can be influenced by rinse water composition. Results of laboratory tests on steel samples are given. In Method A, pinpoint rust was formed by simple exposure to humidity, while in Method B, panels were box annealed, then exposed to humidity. Effects of rinse water on type of rust, alkalinity source of pinpoint corrosion, anions and cations in rinse water on occurrence of pinpoint rust and final rinse on rust formation were among variables studied on black plate panels. Defect was reproduced by using low concentrations of alkali plus certain anions—the worst being chloride. Rinsing off offending ions with distilled water or steam condensate may prevent this form of corrosion. Tables, photomicrographs.—INCO. 11793

3.2.3, 3.5.9

Structure of Oxides Formed on High-Temperature Alloys at 1500 F. JOHN F. RADAVICH. Paper from "Symposium on Basic Effects of Environment on the Strength, Scaling, and Embrittlement of Metals at High Temperatures." ASTM Special Technical Pubn. No. 171, 19-5, 14-31; disc., 32-34. Available from: American Society for Testing Materials, Philadelphia.

A study of the oxide structures formed on various alloys by means of electron microscopy and electron and X-ray diffraction. Tables, micrographs. 13 references.—BTR. 11730

3.4 Chemical Effects

3.4.8, 3.5.9, 8.4.3

Collection and Correlation of High Temperature Hydrogen Sulfide Corrosion Data. A Contribution to the Work of NACE Task Group T-5B-2 on Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry from: The M. W. Kellogg Co., New York, N. Y. G. SORELL AND W. B. HOYT. *Corrosion*, 12, No. 5, 213t-234t (1956) May.

Corrosion by gas mixtures containing hydrogen sulfide at elevated temperatures is reviewed, with particular emphasis on the types of environments present in catalytic reforming and desulfurizing units of petroleum refineries. Data compiled from the published literature, from laboratory and field tests, as well as from pilot and commercial plant experience are summarized and correlated.

Within the general limits of conditions existing in these types of units, corrosion is shown to depend primarily on temperature and hydrogen sulfide partial pressure. Summary curves showing corrosion rates as functions of these two variables are presented as a guide for equipment design.

The corrosion resistance of carbon steel and chrome-moly alloy steels is approximately equal in the environments studied; the 12 Cr stainless steels offer slight improvement but their performance is erratic. The 18 Cr-8 Ni stainless steels possess excellent resistance except under the most severe service conditions. Aluminum coatings are practically immune to hydrogen sulfide attack. There is, however, insufficient experience to appraise their permanence in prolonged service.

The nature and mechanism of hydrogen sulfide corrosion is discussed with special emphasis on the properties of sulfide scales. 11284

3.4.9, 4.6.1, 4.7, 1.6

A Study of the Reaction of Metals and Water (Interim Report). H. M. HIGGINS. Aerojet General Corp. U. S. Atomic Energy Commission Pubn., AECD-3664, April 15, 1955 (Declassified with deletions August 11, 1955), 62 pp.

The molten metals zirconium, Zircaloy-2, uranium, uranium-molybdenum alloy, aluminum, aluminum-lithium- alloy and magnesium were introduced into water in order to determine whether or not violent reactions would result. As long as the molten metals remained as comparatively large globules, the reaction ceased after some surface scale formed. When a means of dispersing the molten metals in water was provided, all those tested except aluminum underwent a violent reaction (uranium and the alloy of uranium and molybdenum were not tested using the dispersal

method). Pressure-time records and other data were obtained which indicate the degree of damage that might be expected from violent reactions of these metals and water. Corrosion-rate tests were made on zirconium, uranium-molybdenum alloy and stainless steel in water at atmospheric pressure. Corrosion-rate tests were made on zirconium and uranium in water vapor at 600 psi. (auth).—NSA. 11545

3.4.9, 2.4.2, 3.5.8

Influence of Moisture on Friction and Surface Damage of Clean Metals. R. O. Daniels and A. C. West. *Lubrication Eng.*, **11**, No. 4, 261-266 (1955) July-August.

New, controlled atmosphere, low speed friction apparatus for fundamental boundary lubrication studies is described. Investigation of effects of moist surrounding atmosphere and bulk water on kinetic friction of high purity, unlubricated metals and theory explaining behavior in terms of oxidizing reaction which occurs at contacting asperities as they deform are given.—BL. 11773

3.5 Physical and Mechanical Effects

3.5.3

Behaviour of Materials Under Cavitation Conditions. (In German.) F. Erdmann-Jesnitzer. *Werkstoffe u. Korrosion*, 6, No. 5, 249; disc., 249 (1955) May; Korrosion VIII Dechema Jahrestagung 1954, **1955**, 127; disc., 127.

Weight loss/time curves were obtained for ferrous and non-ferrous metals as well as for glass, plastics and rubber in a water-cavitation apparatus. In most metals and alloys, after an incubaiton period, cracks develop normal to the surface, first at the grain boundaries in an intercrystalline manner. Later they become intracrystalline. The relation between anisotropy of elastic modulus and cavitation cracking is discussed.—MA. 11782

3.5.3, 7.1

Cavitation Decay on Powerful Hydroturbine Blades. (In Russian.) I. R. Krianin. *Energomashinostroenie*, No. 3, 14-18 (1955) December.

Influence of material and certain construction factors on intensity of cavitating decay of blades. The main cause of decay is the presence of bolt holes. Diagrams, photographs. 5 references.—BTR. 11926

3.5.8

The Contact Resistance and Mechanical Properties of Surface Films on Metals. R. W. Wilson. *Proc. Phys. Soc.* (England), **68**, Pt. 9, 625-641 (1955) Sept. 1.

The nature of the contact between sliding metal surfaces has been investigated by measuring the electrical contact resistance and the coefficient of friction between them. Observations were made over a wide range of conditions which extended down to very light loads of only a few milligrams so that the influence of surface films might be studied. Many noble and base metals have been investigated in both clean and lubicated states. The contact between certain typical pairs of dissimilar metals has also been studied. It was found that at loads below a few grams the oxide film on base metals prevented actual metal-to-metal contact almost entirely. At higher loads the film was disrupted and metallic contact occurred. The change from oxide-on-oxide to metal-on-metal sliding was usually accompanied by changes in the coefficient of friction, the nature of the sliding and the appearance of the track. These experiments have shown that the behavior of oxide, Beilby and lubricant films on metal surfaces follow the same pattern and that a single general picture, based on the theory of the sliding between clean metals at heavy loads, can be given which will describe their influence on the contact and sliding between metals. (auth)—ALL. 11909

3.5.8, 3.5.3

Surface Film Formation and Lubrication. J. K. Lancaster. *Research Correspondence* (Supplement to Research), **8**, No. 7, S33-S35 (1955) July.

Variation of equilibrium contact (electrical) resistance with speed for chromium and a 0.4% carbon steel on tin-base Babbitt were determined, using various lubricants. As the tendency for the metal/lubricant combination to form a protective solid surface film increased, the easier it became for hydrodynamic lubrication to be achieved and hence the "anti-friction" properties improved.—BNF. 11894

3.5.8, 3.5.9

Stress/Strain Curves of Some Metals at Low Temperatures and High Rates of Strain. H. G. Baron. *J. Iron Steel Inst.*, **182**, No. 4, 354-365 (1956) April.

Comparative tensile tests on iron, steel 18/8 stainless, Duralumin (HE14), tough pitch copper, and leaded brass, at 20, —78 and —196 C at strain rates at 10^{-3} and 10^{-5} in./in./sec.—BNF. 11868

3.5.8, 6.3.6

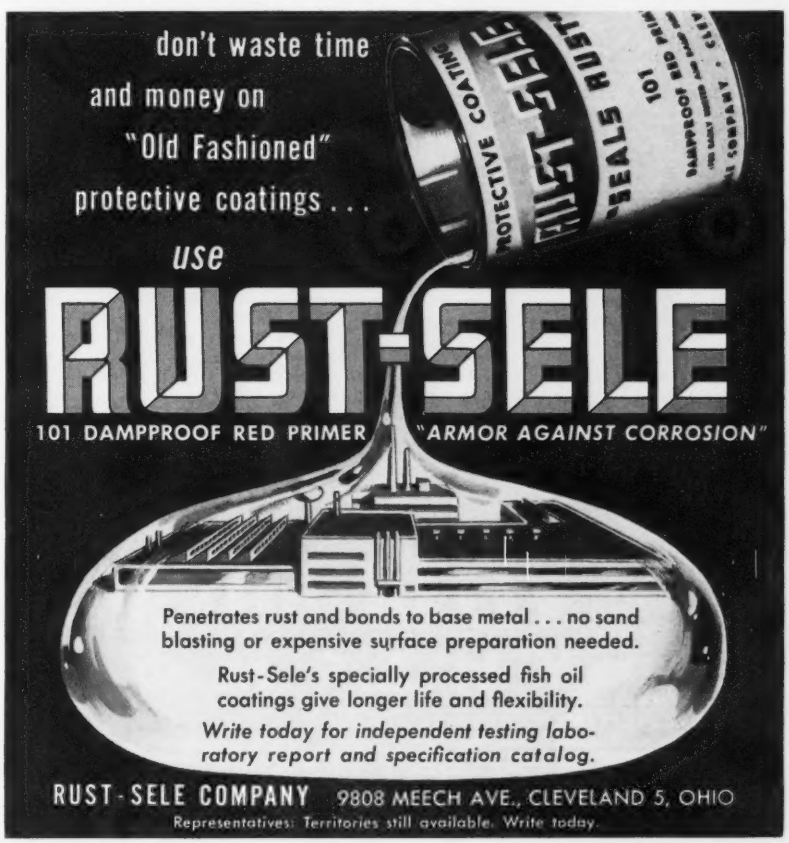
The Problem of Stress Corrosion of Homogeneous Solid Solutions. Part IV. Tensile Properties of Copper-Gold and Copper-Zinc Solid Solutions under the Influence of Mercury and Chemical Reagents. (In German.) L. Graf and H. Klatte. *Z. Metallkunde*, **46**, No. 9, 673-680 (1955) Sept.

Decrease in tensile strength depending on the alloy concentration (maximum at 50 at.% copper-gold and copper-zinc), under the influence of mercury ("solid solution effect" mentioned in Part III) is investigated: similar effect (stress corrosion) with chemical reagents (e.g., 2% ferric chloride solution, ammonia/steam/oxygen, aqua regia), but this shows maxima at 20-25 at.% gold or zinc and disappears at 50%. Pure metals do not show the effect. Raised reactivity of the grain boundary with increasing solid solution and the mechanism and significance of intercrystalline crack formation are discussed with reference to intercrystalline crack formation in stress corrosion.—BNF. 11735

3.5.8, 3.7.3

Stresses in Welded Pressure Vessels. W. P. Kerkhof. *Ingenieur* (Utrecht), **67**, Nos. 45, 46, W131-W138, W141-W148 (1955) Nov. 11, Nov. 18; *Engrs.' Digest*, **17**, No. 1, 24-28 (1956) Jan.; *Welding J.*, **35**, No. 1, 41s-59s (1956) Jan.

Allowable stresses, design stresses and rupture theory for welded pressure vessels and boilers. Definitions of various stresses, limitations and simplifications for calculation, possibilities of failure, plastic deformation, rupture, shear strain theory, internal stresses, total stresses and stress range, stress corrosion, weld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efficiency and weld defects are discussed. Calculations are made for out-of-roundness of cylindrical shells for localized stresses in carbon steel; for allowable stress range for cylindrical shell at 650 F, at atmospheric temperature and between these temperatures; and for domed ends. These calculations are compared with established practice and existing codes. Diagrams, graphs, tables.—INCO. 11759

3.5.8, 7.5.5, 6.2.3

Studies on the Brittle Failure of Tankage Steel Plates. F. J. FEELY, JR., M. S. NORTHRUP, S. R. KLEPPE AND M. GENSAMER. Paper before Am. Welding Soc., Nat'l Fall Mtg., Philadelphia, October 17-21, 1955. *Welding J.*, **34**, No. 12, 596s-607s (1955) Dec.

Final report on investigations into cause of brittle failure undertaken by the Esso Research & Engineering Co. as a result of failure of two large oil storage tanks. Object was to study progress of brittle fractures under conditions similar to those in real structures and to correlate results of such studies with values obtained from conventional tests. Effect of impact energy, effect of plate size, experimental technique of Esso Brittle Temperature test, backing-up effect, effect of localized cooling, independence of stress requirement and crack size, Griffith theory and nature of long cracks in steel plates are discussed. Effects of plate thickness and chemical composition are considered in evaluation of tank steels. Summary is made of the chemical, physical, Charpy impact values, grain sizes and Esso Brittle Temperature for all the steels tested. Correlation is shown between Esso Brittle Temperature and Charpy V-notch impact temperature. Tables, graphs.—INCO. 11781

3.5.9, 4.2.3, 4.3.3

The Effects of Contamination by Vanadium and Sodium Compounds on the Air-Corrosion of Stainless Steel. G. W. CUNNINGHAM AND ANTON DES. BRASUNAS. *Corrosion*, **12**, No. 8, 389t-405t (1956) August.

The acceleration of high temperature corrosive attack on heat-resistant alloys caused by the presence of vanadium compounds is well established. The progressive addition of sodium sulfate to the vanadium contaminant indicates that the most corrosive mixture is approximately 20 percent sodium sulfate—80 percent vanadium pentoxide. The survey of the melting temperatures of various vanadium pentoxide—sodium sulfate mixtures shows no direct correlation to corrosive behavior. There appears to be a strong indication, however, that unusually high oxygen solubility in the molten contaminant containing 20 percent sodium sulfate may be responsible for its unusually high corrosiveness. This makes it possible to postulate a more satisfactory theory of the mechanism of corrosive attack which need not involve a solid phase at the reaction interface.

Additions of calcium oxide, strontium oxide and carbon were particularly effective in reducing the intensity of attack. The effectiveness of carbon is restricted to short time intervals during which it became oxidized. 11929

3.6 Electrochemical Effects

3.6.2, 6.3.15, 3.8.3

The Role of Crevices in Decreasing the Passivity of Titanium in Certain Solutions. DAVID SCHLAIN AND CHARLES B. KENAHAN. *Corrosion*, **12**, No. 8, 422t-426t (1956) Aug.

Crevices increase the tendency of titanium to corrode in certain solutions in which it normally is made passive by air. This increase in the corrosion rate occurs most consistently in air-saturated 1 N sulfuric and 1.6-1.75 N hydrochloric acid solutions. Corrosion is not confined to crevices but appears to be uniform over the entire surface. An explanation is presented. 11930

3.6.8, 4.3.2

Oxygen Overvoltage in Concentrated Acid Solutions. Part I. Perchloric Acid. T. R. BECK AND R. W. MOULTON. *J. Electrochem. Soc.*, **103**, No. 4, 247-252 (1956) April.

Oxygen overvoltage was measured on platinum electrodes in 5M perchloric acid from —45 to +40 C and in 0.005-9M perchloric acid at 0 C. A limiting current density that was found is due to activation overvoltage at the anode surface. This limiting current density decreased at lower temperatures and in higher perchloric acid concentrations. It also marked the beginning of ozone formation. Adsorption of perchlorate ions is believed to be the cause of the limiting current density. Illustrations.—INCO. 11869

3.7 Metallurgical Effects

3.7.3

Six Ways Wire Thread Inserts Improve Fastener Performance. P. E. WOLFE AND A. H. MUSSGNUG. Heli-Coil Corp. *Materials & Methods*, **42**, 112-115 (1955) Oct.

Standard wire-thread inserts coiled from 18/8 (AMS 7245) stainless steel wire of diamond cross section solve many fastening problems. They provide higher loading strengths than do standard tapped threads in the same material. Because of the smoother rolled surface, they are less susceptible to and cause less frictional wear at mating surfaces. They lock themselves into the tapped hole and thus prevent wear caused by equipment vibration. The hard, dense surface also renders them immune to seizing and galling, even up to 800 F. Inserts in chromate-treated and lacquered C-T6 magnesium castings showed no galvanic corrosion in 200-hr. salt spray; in similarly treated 356-T6 cast aluminum, there was no corrosion after 500-hr. salt spray. The stainless-steel inserts completely solved the corrosion problem in aluminum housings for radar scanners exposed in arctic and marine atmospheres. They are smaller in diameter than solid bushings and require less space for installation. This, in addition to their ability to strengthen threads in soft materials, has made it possible to use lighter metals and plastics in various products and to reduce the weight and space of entire assemblies.—PDA. 11873

3.7.3

Interface Phenomena During Brazing. KARL M. WEIGERT. *Metalloberflache*, Sec. A, **9**, No. 3, 44-45 (1955).

Cf. *Welding J.*, **34**, No. 5, 420 (1955). A brief review of the constitution and the mechanical properties of silver brazing alloys (silver-copper-zinc and silver-copper-cadmium) and the manner in which such materials may react with the metals of the components during brazing operations—which may cause alterations in corrosion-resistance, intercrystalline diffusion with nickel alloys resulting in embrittlement and the generation of internal stresses with the consequent liability to stress-corrosion. 8 references.—MA. 11825

3.7.3

Preliminary Investigation of Properties of High-Temperature Brazed Joints Processed in Vacuum or in Molten Salt. C. A. GYORGAK AND A. C. FRANCISCO. National Advisory Cttee. for Aeronautics, Tech. Note 3450, May, 1955, 29 pp.

Shear joints in high alloy steels were brazed with nickel-chromium-silicon-boron alloy in a salt-bath and in vacuum. Brazing times and temperatures were varied and the effects of an (unspecified) protective coating on the base metals and addition of nickel powder to the brazing alloy (to reduce erosion) were studied. —BNF. 11800

3.7.3, 7.7

Performance of Joints in Steel and Non-Ferrous Conduits and Fittings (Excluding Copper). L. GOSLAND. E.R.A. Tech. Rep. V/T 119, 1955, 18 pp. British Electrical and Allied Industries Research Association, Thorncroft Manor, Dorking Road, Leatherhead, Surrey.

Results of 18 months' tests under various conditions. There was little deterioration in electrical continuity of joints made from any combination of aluminum alloy, zinc alloy or steel conduit and fittings, providing the joints were tight and the threads were greased immediately on cutting. An appendix gives the results of similar tests made by Tube Investments Ltd.—BNF. 11741

3.7.3, 3.5.8

Researches on Fatigue of Metals at Mechanical Engineering Research Laboratories. East Kilbride. C. E. PHILLIPS. *Trans. Inst. Engrs. Shipbuilders Scot.*, **99**, No. 3, 173-192 (1955-1956).

Investigations since the establishment of the laboratory in 1950 have included work on pin joints, screw threads, fatigue crack propagation, low endurance fatigue studies. Reference is made to steel and to aluminum. Attention is drawn to gaps in existing knowledge and indication given of useful directions for further research.—BNF. 11908

3.7.3, 3.5.8

Correlated Fatigue Data for Aircraft Structural Joints. R. B. HEYWOOD. Aeronautical Research Council Tech. Rept. C.P. No. 227, June, 1955, 9 pp. Available from: H. M. Stationery Office, England.

Results of fatigue tests carried out at the Royal Aircraft Establishment on typical aircraft wing structural joints are correlated to give an indication of general fatigue behavior. Results are given as S-LogN curves and indicate that no single factor, e.g., type of aluminum alloy, U.T.S. or mean stress of fatigue cycle can indicate the mode of behavior.—BNF. 11823

3.7.3, 6.4.2

Effect of Cold-Rolling on Corrosion of Aluminum-Copper Alloys. M. MIKAMI AND K. HASHIURA. *J. Japan Inst. Metals*, **19**, No. 7, 442-444 (1955) July.

Refers to an experiment made to investigate relations between cold-rolling and corrosion of solution-treated aluminum-copper alloys in 10% hydrochloric acid solution at 30 C. Measuring the volume of hydrogen produced in the reaction gave the following results: 1) Corrosion increased with copper content

of the alloys. 2) Cold-rolling decreased corrosion of the alloys to some degree, but further cold working increased corrosion.—JSPS. 11881

3.7.4, 6.3.6

Structure-Dependent Chemistry of Metal (Copper) Surfaces. W. D. Robertson, "Impurities and Imperfections" (Am. Soc. Metals), 1955, 170-185.

Investigations into the stability of crystallographic planes of copper by study of copper/mercury cells and the structure-dependence of chemical reactions such as etching which occur at the surfaces of pure metals and alloys are reviewed. The effects of dislocations, grain boundaries, solute atoms and slip bands on reaction rate are described. 15 references.—MA. 11912

3 8 Miscellaneous Principles

3.8.2, 6.2.2, 6.3.10

Electrochemical Properties of Alloys. Part V. On the Anodic Behavior of Iron-Nickel Alloys in Sulfuric Acid Solution. S. Morioka and K. Sakiyama. *J. Japan Inst. Metals*, **19**, No. 1, 31-34 (1955) Jan.

A series of anodic polarization tests on iron-nickel alloys with varying nickel content were carried out in sulfuric acid solution. Results obtained: 1) The higher the nickel content, the greater the polarization for anodic dissolution of active alloys. Increase in nickel favored the onset of anodic passivity of the alloy anodes. 2) When a passive condition is reached the anodic dissolution of iron and iron-rich alloys of less than about 60% nickel ceases almost entirely; anodic dissolution of nickel and nickel-rich alloys of more than about 60% nickel does not cease entirely, the dissolution of the latter being due to the greater anodic oxidation, the higher the nickel content and the higher the anode potential. 3) Iron-nickel alloys passivated by anodic polarization are only temporarily passive. 4) In sulfuric acid solution the α-phase alloys containing less than 30% nickel were found to be about 0.15-volt less noble than the γ-phase alloys containing more than 30% nickel. 5) The formation of the ordered lattice Ni_3Fe in alloys reduced the anodic dissolution of the alloys.—JSPS. 10915

3.8.2, 6.3.21

Experiments on the Interface Between Germanium and an Electrolyte. W. H. Brattain and C. G. B. Garrett. *Bell System Tech. J.*, **34**, No. 1, 129-176 (1955).

Electrode potentials, V, or ρ- and η-type germanium in contact with aqueous solutions of potassium hydroxide, potassium chloride and hydrochloric acid were measured as a function of anodic and cathodic current, and of incident light intensity. For anodic currents, V comprises three parts, viz. i) the reversible electrode potential corresponding to the anodic reaction, depending only on the solution; ii) an overvoltage of the usual form; and iii) a term, $kT/e \log (\rho_i/\rho)$, where ρ is the equilibrium hole concentration and ρ_i is the concentration just inside the space-charge region of the germanium. The anodic current is determined by the flow of holes to the surface, so that the current saturates for η-type germanium, but not for ρ-type. The saturation current is determined by body- and surface-generation of holes and by the creation of excess holes by light. There is a current gain of 1.4-1.8; in addition there is a small "leakage" current not dependent on hole supply. Similar statements can be made for cathodic current, except that V and current are determined, respectively, by concentration and supply of electrons instead of holes; current gain is ~1 and the leakage current is larger. Complicating time-effects characterize cathodic but not anodic currents. The results are interpreted in terms of simple thermodynamic theory, and a comparison is made with results obtained by Brattain and Bardeen [*ibid.*, **32**, 1 (1953)] relating to the germanium/gas interface to which similar considerations apply. The surface recombination velocity at the surface of an η- or ρ-type germanium surface in contact with an electrolytic is $\gg$ a few hundred cm/sec. and is less when passing anodic than cathodic current. 20 references.—MA. 11416

3.8.2, 3.8.3, 6.2.2

The Corrosion of Passive Iron in Acid Solutions. Klaus J. Vetter. *Z. Elektrochem.*, **59**, No. 1, 67-72 (1955).

The overall reaction for the corrosion of passive iron is given as $Fe \rightarrow Fe^{+3} + 3e^-$. The reaction $Fe^{+2} \rightarrow Fe^{+3} + e^-$ is not the mechanism, since it is at least 5% too slow. A linear relation is obtained between pH and corrosion current density. From this the rate-controlling reaction is found to be: Fe^{+3} (oxide) $\rightarrow Fe^{+3}$ (ag.). A relation is obtained between passivation time and corrosion equivalent current density. 14 references.—MA. 11808

3.8.2, 5.2.1

Conventions for the Use of Certain

Electrochemical Terms. 1) T. P. HOAR AND F. WORMWELL. 2) LAWRENCE WHITBY. 1) *Chemistry and Industry*, No. 23, 642-643 (1955). 2) *ibid.*, No. 34, 1064 (1955).

Hoar and Wormwell present suggestions designed to avoid the confusion occasionally resulting from the use of different conventions for the sign and nomenclature of electrode potentials, with particular reference to cathodic protection. Whitby criticizes some of the proposals.—MA. 11754

3.8.4

Mechanism of Oxygen Transfer Through Thin Electrolyte Layers. (In Russian.) *Doklady Akad. Nauk SSSR*, **104**, No. 6, 876-879 (1955) October 21.

Proves, by experiments, that usually irregular evaporation of electrolyte from the metal surface facilitates stirring of thin electrolyte layers. This fact results in decreasing diffusion layer thickness and in increasing oxygen supply to the metal surface. Tables, graphs. 14 references.—BTR. 11832

3.8.4, 4.6.1, 6.3.20

Mass Transfer of Foreign Elements from Zirconium During High-Temperature Water Corrosion. L. M. LITZ, S. A. RING, W. R. BALKWELL AND R. D. NETHAWAY. California Research and Development Co. U. S. Atomic Energy Commission Pubn., LRL-76, January, 1954 (Declassified Sept. 29, 1955), 19 pp.

The mass transfer of niobium, zirconium, yttrium, strontium, rubidium, selenium, arsenic and germanium from zirconium metal foils was followed during water corrosion of the zirconium at 264, 280 and 300 C, using radioactive tracers of these elements. Diffusion appears to be the predominant transfer process with a decrease in diffusion rate as the corrosion film increases in thickness. Approximate diffusion coefficients were calculated. (auth)—NSA. 11732

3.8.4, 6.3.14, 3.2.2, 5.8.3

The Corrosion of Tin in Solutions of Sodium Alkyl Sulphates. T. K. ROSS. *J. Applied Chem.*, **5**, 10-18 (1955) January.

Mechanism of pitting corrosion in solutions containing surface active agents. Graphs, micrographs. 22 references.—BTR. 9222

3.8.4, 1.6

Chemisorption. B. M. W. TRAPNELL. Book, 1955, 265 pp. Butterworths Scientific Publications, London.

Under the heading of Chemisorption come most of the adsorption phenomena on metals that play an important part in the mechanism of processes in solution and in the gas phase and, therefore, are necessary in the theory of bright plating, e.g., as well as of thermal diffusion and vacuum deposition techniques. In the present book the author surveys the experimental methods and deals with velocities of adsorption and desorption, isothermic heat of adsorption, mechanism of adsorption, mobility of adsorbed layers and related catalytic reaction.—EL. 11021

3.8.4, 3.6.4, 3.4.6

The Effect of Gases on the Contact Potentials of Evaporated Metal Films. NORMAN HACKERMAN AND EMERSON H. LEE. *J. Phys. Chem.*, **59**, No. 9, 900-906 (1955) September.

The effect with time of oxygen, nitrogen, water vapor and air on the contact potential differences between aged bulk platinum and evaported metal films was studied by the vibrating condenser method. The metals used were aluminum, lead, nickel, chromium and iron. Both reversible and irreversible effects were observed. An explanation is offered based on adsorption of the gases which provides either a dipole barrier or an ion barrier to the emission of electrons. (auth).—ALL. 11065

3.8.4, 6.3.21, 2.3.6

A Study of the Etching Rate of Single-Crystal Germanium. PAUL R. CAMP. *J. Electrochem. Soc.*, **102**, No. 10, 586-593 (1955).

It was found that an aqueous solution of hydrogen peroxide and hydrofluoric acid is a reliable etchant for germanium and data are given for the etching rate as a function of temperature and composition of the etchant and of orientation and purity of the crystal. An equation which assumes two reactions taking place in sequence on the surface fits the rate/temperature data within the limits of experimental error. From etching data, the thickness of the disturbed surface layer due to abrasive grinding was found to be in the range 2-10μ.—MA. 11900

4. CORROSIVE ENVIRONMENTS

4.2 Atmospheric

4.2.3, 4.3.3

Effects of Sulphate-Chloride Mixtures in Fuel-Ash Corrosion of Steels and High-Nickel Alloys. H. T. SHIRLEY. *J. Iron Steel Inst.*, **182**, 144-153 (1956) Feb.

Effect of composition and temperature on various heat-resisting materials was studied for a range of alkali and calcium sulfate-chloride mixtures. Micrographic characteristics of the attack were investigated. Photograph, micrographs, tables. 5 references.—BTR. 11676

4.2.3, 8.4.2, 1.6

Literature Review and Design Studies of Gas Appliance Venting Systems. T. E. HAMPEL AND R. L. STONE. Am. Gas Assoc. Labs., Research Bull. No. 68, April, 1955, 246 pp.

Results of field surveys on chimney damage are included. Glazed sewer pipe, cast iron, asbestos and lead were recommended as suitable lining materials in a paper issued in 1928. A survey of 94,000 gas burner installations, published in 1937, stated that only 4.8% used lined chimneys, with vitreous enamel the most promising liner. Further field studies covering results obtained up to January, 1951, indicate aluminum to be the most resistant of those liners for which damage percentages are tabulated (plastic-coated steel, vitreous enamel-coated steel, Transite, Payne liner, aluminum). Another 1951 study reported that stainless steel was the most corrosion-resistant material of a group including: low-alloy high-yield strength steels, 5 chromium steel, cast iron, copper, brass, zinc, 2-S aluminum, aluminum painted steel, ternecoated steel and Alclad 24 ST. Tables, graphs, 108 references.—INCO. 11897

4.2.3, 8.4.2, 1.6

Research in Pilot Burner Design, Construction and Performance. Bulletin II. The Effect of Pilot Burner Assembly Materials and Gas Composition on Pilot Burner Outage at Elevated Temperatures. J. C. GRIFFITHS. Am. Gas Assoc. Labs., Research Bull. No. 69, April, 1955, 62 pp.

Analyses of deposits found in pilot burner assemblies revealed oxides, sulfides and carbon as the chief causes of blockage. Aluminum minimized cracking of unsaturated hydrocarbons as well as corrosion. Temperatures at which various gases formed deposits on several pilot assembly materials were observed. Substitution of yellow brass tubing for copper tubing was found to be desirable. For metal temperatures lower than 1000 F, aluminum was the most satisfactory material studied. Nickel-free stainless steel is suggested for use at metal temperatures exceeding 1000 F. Diagrams, graphs, tables.—INCO. 11785

4.2.7

Choice of Materials and Surface Protections for Tropical Climate. (In Czech.) K. BARTON. *Strojirenstvi*, **5**, No. 6, 463-466 (1955) June.

Corrosion of metallic parts through atmospheric factors, including tropical moisture, rain and light; comparison of nickel- and chromium-plating and zinc, cadmium and organic coatings; evaluation of parts made of stainless steel, zinc, copper, silver, aluminum and magnesium alloys. Table, 10 references.—BTR. 11882

4.3 Chemicals, Inorganic

4.3.1, 4.4.1, 4.7, 3.5.9

Corrosion by Transfer Liquids. M. R. BIGEON. Paper before Assoc. des Ingenieurs en Anti-corrosion, Paris, October 14, 1954. *Corrosion et Anti-Corrosion*, **3**, 116-124 (1955) May-June.

Gives data on corrosion by tanrsfer fluids with positive action, i.e. fluids for heating containers, etc., in which energy transformation reactions occur, e.g. saturated water vapor, superheated water, chlorinated hydrocarbons, polyglycols, mineral oils, organosilicates, aromatic hydrocarbons and oxides, mercury, lead, gallium and fused salts. Long-time tests showed that aryl orthosilicates do not corrode nickel, mild steel, copper or bronze. "HTS" penetrated 0.00254 mm per month into Monel and inappreciably into 1% niobium-18/8 steel, 2.4% molybdenum-18/8 steel, Inconel, at 545 C; for 545-600 C, mild steel must be replaced by high-chromium steels, 18/8, or low-chromium steels containing aluminum or silicon. Catastrophic corrosion seems to have led to abandonment of use of "NS" (aluminum chloride-sodium chloride mixture).—INCO. 11726

4.3.2, 4.4.8, 8.8.1

Keys to a New Chemical Kingdom. *Chem. Eng.*, **63**, No. 1, 199-202 (1956) Jan.

To bring nitroparaffin production to commercial fruition, equipment had to be designed for vaporizing nitric acid under pressure, reacting nitric acid vapors with hydrocarbons at high temperature, recovering nitric oxide from nitration gases, recovering, purifying and separating nitroparaffins produced and making their derivatives. Corrosion control is of utmost importance. No standard alloy gave exact combination of corrosion resistance and physical properties needed for much of equipment. Tendency of stainless steel to catalyze oxidation reactions is combated by continuous deactivation treatment. Corrosiveness of nitroparaffins to steel and discoloration by impurities is eliminated by a chemical purification process. Among chemical

engineering achievements scored in connection with derivative plant is evolution of safe procedures for handling Raney nickel pyrophoric catalyst, including its reactivation and recycle. Flow sheets.—INCO. 11583

4.3.5, 6.3.6, 3.8.4

The Kinetics of the Reaction of Elementary Fluorine with Copper Metal. H. E. BROWN, J. M. CRABTREE AND J. F. DUNCAN. *J. Inorganic and Nuclear Chem.*, 1, 202-212 (1955) June.

Studied under high vacuum from room temperature to 250 C and from 6 to 60 mm. Hg pressure. Tables, graphs, diagram. 10 references.—BTR. 11922

4.5 Soil

4.5.3, 8.9.3

An Anomaly in Pipe Line Corrosion Diagnosis. L. P. SUDRABIN. *Corrosion*, **12**, No. 3, 99t (1956) March.

Observations in pipe line survey; a 400-foot long 4-inch hot water (170 F) line, two years in sand backfilled area. Tables.—BTR. 11562

4.5.1

Theoretical Principles of Metal Corrosion in Soil. T. MARKOVIC AND Z. DUGI. *Nafta* (Yugoslavia), **6**, 175-179 (1955) June.

Corrosion of iron in soil was studied as a function of the ratio of water to soil atmosphere, to determine the effect of water saturation. Oxygen transport was slower in unsaturated than in saturated soils and the reaction order of iron decomposition in the soil varied with changes in the water-soil atmosphere ratio. 11833

4.5.3, 5.2.1

Earth Potential or Surface Potential Gradient Tests on Buried Cables. DANIEL R. WERNER. *Corrosion*, **12**, No. 8, 376t-384t (1956) Aug.

Earth potential or surface potential gradient tests, their types, uses and limitations are discussed. Topics covered include range of potentials, selection of areas for tests, installation of remedial measures on buried telephone cables, determination of buried structure location and meter circuits for measuring potential gradients. Data are given also on hot spot areas, changes in insulation resistance of the covering on a buried cable and interference effects on other buried structures and railroads from cathodic protection installations. 11885

4.5.3, 8.9.3

The Sui Gas Pipeline: Details of Corrosion Survey. G. MCHARDY AND R. C. J. WINDEBANK. *Petroleum*, **18**, No. 9, 341 (1955) Sept.

Soil resistivity measurements at several depths at frequent intervals and analysis of representative soil samples. 11834

4.7 Molten Metals and Fused Compounds

4.7, 3.8.4, 5.8.3

The Significance of Wetting in Reactor Technology. J. W. TAYLOR. Atomic Energy Research Establishment, Harwell, Berks, England. *J. Nuclear Energy*, **2**, 15-30 (1955) Aug.

The fundamental forces responsible for the spreading of a liquid metal on a solid (or a liquid) surface are discussed and a number of interfacial tension and spreading studies are analyzed in terms of the theoretical considerations. In the

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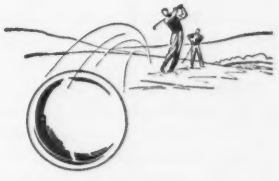

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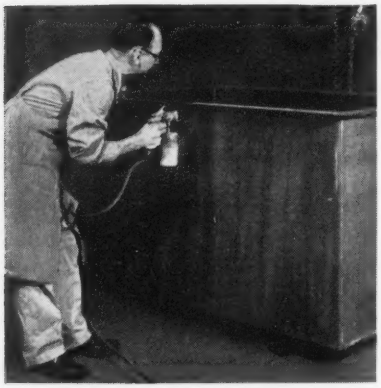

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light of these, methods of modifying the interfacial tension in any given application are suggested. The significance of interfacial effects in the following technological processes is outlined: liquid metal corrosion and intergranular penetration; heat transfer; mass transfer and zone melting; liquid metal slurry properties and stability; and extraction metallurgy. (auth)—NSA. 11843

4.7, 6.3.11

Transformation and Equilibrium States in Alkali-Hydroxide Melts. Part I. Effects of Alkali-Hydroxide-Melts on Gold, Silver, and Platinum. (In German.) HERMANN LUX AND TITUS NIEDERMAIER. *Z. anorg. u. allgem. Chem.*, **282**, No. 1/6, 196-209 (1955) Dec.

Investigation of effect of melts at 410 C, with a definite oxygen and hydrogen content in the gas-phase. Tables, diagrams. 12 references.—BTR. 11878

4.7

The Behavior of Materials in Aggressive Liquid Metals. DAVID H. GURINSKY. Paper from Nuclear Metallurgy, IMD Special Report Series No. 2, 1956, 5-20. American Institute of Mining and Metallurgical Engineers, New York.

Summarizes available information on the corrosive attack of mercury, molten lead and bismuth on common construction materials. Graphs, diagrams, tables. 18 references.—BTR. 11634

4.7

Corrosion of Materials in Fused Hydroxides. G. P. SMITH. Paper from Nuclear Metallurgy, IMD Special Report Series No. 2, 1956, 71-94. American Institute of Mining and Metallurgical Engineers, New York.

Some of the fused alkali metal hydroxides are of potential interest in reactor technology, both as coolants and as moderators. This review is concerned with kinds of corrosion phenomena which have been observed in ceramics and in metals. Micrographs, photographs. 50 references.—BTR. 11674

4.7, 1.6

Progress Report No. 31 for October and November 1955. W. J. POSEY, ed. Mine Safety Appliances Co., Callery, Pennsylvania, December 12, 1955, 72 pp.

Testing of the 3-Mw steam generators was continued. Level indicators for liquid sodium, combined valve connect and disconnect and AC induction pumps for liquid metals are described. Microfissure propagation has been observed as a result of quenching heated weld specimens with liquid sodium. The feasibility of using impure nitrogen as a cover gas for sodium systems was demonstrated. Investigations were continued on the corrosion of zirconium by liquid sodium, the removal of mercury from sodium systems by amalgamation with copper and the radiation hazards arising from leaks in liquid metal systems.—NSA. 11523

4.7, 6.2.2, 3.2.3

Corrosion of Iron by Oxygen-Contaminated Sodium. G. W. HORSLEY. *J. Iron Steel Inst.*, **182**, Pt. 1, 43-48 (1956) Jan.

To investigate the corrosion mechanism of iron in oxygen-contaminated sodium, corrosion product was isolated and compared with compounds prepared by heating mixtures of sodium oxide and iron powder in vacuo. Corrosion studies were carried out in all-welded, electropolished or bright-pickled stainless steel pots, using nickel crucible for low oxygen concentrations and dead mild steel crucible for higher concentrations. Observed effects on spectrographically pure iron after immersion in sodium at 800 C for seven days are tabulated. Results showed that oxygen concentrations over 0.3 were required to produce appreciable scaling on the iron. Further experiments were carried out with sodium containing 5% oxygen in which samples suffered extensive corrosion. Brown scale formed was loosely adherent and was scraped off after washing specimens in ethyl alcohol to remove sodium. Largest component of corrosion product was $(Na_2O)_2{\cdot}FeO$. Tests made in distilled sodium show reduction of $(Na_2O)_2{\cdot}FeO$ and indicate that stability of this compound is governed by activity of oxygen in the metal. Tables, photomicrographs, x-ray powder photographs. —INCO. 11635

4.7, 6.2.3, 3.7.4

The Corrosion of Carbon-Containing Iron by Iron-Saturated Molten Zinc. D. HORSTMANN. *Arch. Eisenhuttenw.*, **27**, 85-93 (1956) Feb.

Time and temperature effects in corrosion of carbon-containing irons (up to 2.08%) (really mild steels) by iron-saturated molten zinc, with particular reference to role played by structure of steel. Structures investigated included steels containing spheroidal pearlite.—INCO. 11622

5. PREVENTIVE MEASURES

5.1 General

5.1

The Prevention of the Corrosion of Ferrous Metals. J. C. HUDSON. *J. Inst. Elec. Engrs.*, **2**, 84-88 (1956) Feb.

Mechanism of corrosion; rust prevention by alterations in corrosive medium, design, or composition of metals; application of protective coatings; cathodic protection. Graph, micrographs, photograph. 8 references.—BTR. 11598

5.2 Cathodic Protection

5.2.1, 8.9.3

System-Wide Cathodic Protection. M. G. MARKLE. Am. Gas Assoc. Distribution, Motor Vehicles and Corrosion Conf., Cincinnati, April 12-15, 1955. *Pipe Line News*, **27**, No. 9, 52, 54, 56, 58, 60 (1955) Sept.; *Gas*, **31**, No. 10, 99-101, 104, 106 (1955) Oct.

Experience with Northern Illinois Gas Co.'s 8,600,000 ft. of cathodically protected pipe is reported. Magnesium anodes were installed nearly throughout, rectifiers being used rarely. Soil pre-testing was usually omitted. All pipes were mill coated with a minimum of 3/32-inch of plasticized coal tar reinforced with glass and all joints and fittings wrapped with coal tar tape. 11739

5.2.2, 8.9.5

The Performance of a Cathodic Protection System on the USS Ingraham (DD 694) December 1953—January 1955. L. J. WALDRON AND M. H. PETERSON. Naval Res. Lab., Rept. No. 4636, September 30, 1955, 6 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order P.B. 111,742).

Magnesium-anode cathodic protection system installed on the USS Ingraham in December, 1952 and renewed in De-

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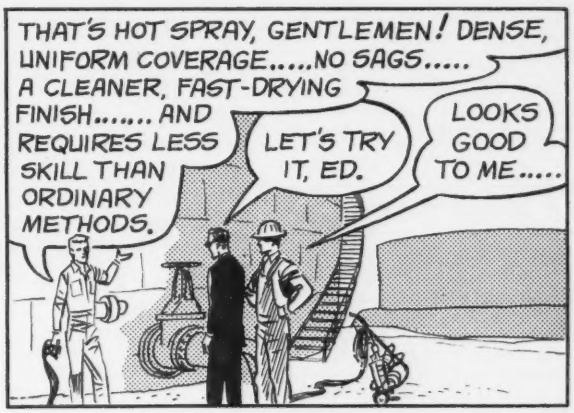
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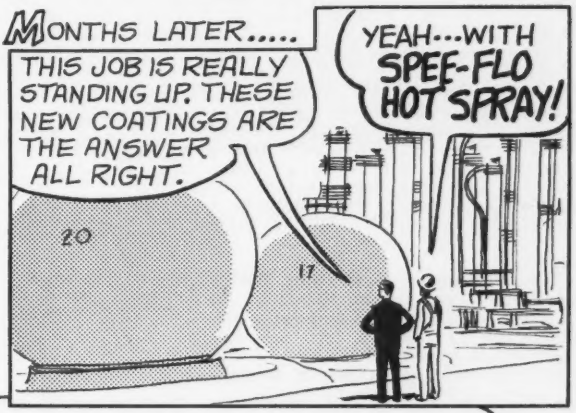

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cember, 1953 has proved to be almost 100% effective in eliminating corrosion of the underwater hull and 90% effective in protecting rudders, shafts and struts. Magnesium anodes deteriorated less during second year of test but were 60% exhausted after 14 months. Vinyl paint on hull was in fair condition and showed little additional deterioration during second year. Current requirements were essentially constant during second year of test. Graphs.—INCO. 11815

5.2.3, 7.10

Cathodic Protection and Its Result on the Sheet-Pilings of Nagoya Port. M. NAKAGAWA. *Corrosion Engineering*, **4**, No. 4, 171-175 (1955) Aug.

Cathodic protection was applied to the sheet pilings of Nagoya Port in September, 1954. A current of 800 amperes from four selenium rectifier units was supplied to an area of about 160,000 sq. ft. (including both sides of sheet pilings).

Protection was confirmed by means of potential measurement and weight loss determination of test pieces immersed at various depths in sea water.—JSPS. 11865

5.3 Metallic Coatings

5.3.4

Metallizing, by the Spray Method, in the Repair of Equipment. (In Russian) A. M. EDEL'SON. *Vestnik mashinostroeniia*, **36**, No. 1, 66-67 (1956) Jan.

Advantages, economy and techniques of repairing wire-drawing band surfaces by metallizing, rather than by dechromizing and rechromizing. Diagram.—BTR. 11644

5.3.4

Ferrocyanide Electrolyte for Silver Plating. (In Russian.) V. I. SEMERYUK. *J. Applied Chem.*, USSR (Zhur. Priklad. Khim.), **28**, No. 11, 1240-1242 (1955) Nov.

Compact, fine-grained, adherent deposits of silver were obtained from a bath containing silver chloride, potassium ferricyanide and potassium carbonate; the silver is thought to be present as $KAg(CN)_2$.—BNF. 11541

5.3.4

The Mechanism of Leveling during the Electrodeposition of Nickel in the Presence of Organic Compounds. H. LEIDHEISER, JR. Virginia Inst. Sci. Res. Paper before German Bunsen-Society for Phys. Chem., Gen. Mtg., May 19-22, 1955. *Z. Elektrochem.*, **59**, No. 7/8, 756-765; disc., 766 (1955).

Object of study was to understand mechanism of leveling and to correlate structure of organic compounds with their ability to cause leveling of surface. Experiments were conducted on: deposition on sharp tips, over isolated scratches and projections and on wires of different diameters; the effect of variables on leveling rate; and relation of leveling to cathode potential. The plating solutions used were Watts bath, Perflow bath (semi-bright) and Modified XXX (fully bright), the latter 2 sold by the Harshaw Chem. Co. The rate of scratch-filling increased with an increase in the polarization of the cathode. In commercial nickel plating, rate of leveling increased with increase in pH and temperature and with decrease in current density and in width of scratch at constant rate. Mechanism of leveling during continuous electrodeposition is explained in terms of migration of nickel ions or nickel atoms over the surface. Photomicrographs, graphs, tables.—INCO. 11445

5.3.4

Change in the Degree of Roughness of the Surface of Electrodeposited Copper Depending on the Different Conditions of Electrolysis. (In Russian.) N. P. FEDOT'EV AND N. P. GNUSIN. *J. Applied Chem., USSR* (Zhur. Priklad. Khim.), **28**, No. 11, 1237-1240 (1955) November.

Effect of temperature, current density, bath composition and superimposed alternating current, on the roughness of deposits from acid cupric sulfate baths.—BNF. 11378

5.3.4

Progress in Electroplating. A. KUTZELNIGG. *Werkstoffe und Korrosion*, **6**, 577-580 (1955) December.

Review of progress in electroplating since 1945 includes bright and levelling deposits, automatic plating installations, degreasing, nickel, chromium and zinc plating, passivation, nickel substitutes and anodic brightening.—INCO. 11434

5.3.4

The Protection of Structural Steel. Parts I, II. Practical Experience of Protection by Sprayed Metal Coatings. W. E. BALLARD AND F. A. RIVETT. *Chemistry & Industry*, No. 50, 1606-1615 (1955) Dec. 10.

Techniques of applying zinc and aluminum coatings for maximum possible protection. Photographs, table.—MR. 11306

5.3.4, 1.3

A Survey of the Literature on the Electrodeposition of Molybdenum. T. T. CAMPBELL AND A. JONES. U. S. Bureau of Mines Information Circular No. 7723, July, 1955, 6 pp.

Electrolytic extraction and electroplating of molybdenum from aqueous and nonaqueous solutions and fused salt systems. Based on 33 references up to 1954.—BNF. 11396

5.3.4, 6.3.19

Heat Treatment Improves Plating on Zinc Die Castings. W. G. STEPHENSON, JR. *Products Finishing*, **20**, No. 4, 28-30, 32, 34 (1956) January.

Use of proper heat treatment to prevent troublesome blemishes, such as run pattern, cold shot, solder spots and blisters, on zinc die castings, which cause difficulty in plating. Heat treating for 1 hour at 410-425F breaks up dendritic structure of surface skin on zinc casting and produces more evenly dispersed grain. Buffing after nickel plating dropped from 48% to 13%. —INCO. 11375

5.3.4

Corrosion Effects in Electroplated Coatings. (In German.) E. RAUB. *Mitt. Forschungsgesellschaft Blechverarbeitung*, No. 1, 8-11 (1955) Jan. 1.

Illustrates and discusses a number of cases of corrosion of electro-deposits arising from bad practice, including stains on work from cyanide baths owing to bath residues (silver and brass deposits); black stains on tin coatings over nickel; staining of brass by packing materials; white rust on zinc; platings on zinc die-castings; chromium- or chromium-nickel on brass.—BNF. 11920

5.3.4

Growth Layers in the Reaction Between Solid Iron and Molten Aluminium and Aluminium Alloys. (In German.) G. GURTLER AND K. SAGEL. *Z. Metallkunde*, **46**, No. 10, 738-741 (1955) Oct.

Effect of molten aluminum and alloys at different temperatures (730-920C) on solid iron (Armco and cast) dipped into the molten metal for a few minutes or seconds (Alfin process). Aluminum, aluminum-silicon (up to 13.5% silicon) and aluminum-zinc (up to 20% zinc) were used. Results are recorded indicating type of alloy layer formed, beta-phase (Al_5Fe_2) and/or delta-phase (Al_3Fe). It is shown that the presence of delta except in very small amounts is always detrimental to the strength or adhesion of the coating. For aluminum-zinc alloys, low zinc-contents and low temperatures (about 730C) are recommended to prevent formation of delta. —BNF. 11779

5.3.4, 5.9.1

Some Observations on the Problem of the Nature and the Treatment of Metal Surfaces. H. WIEGAND. *Metalloberflache*, Sec. A, **9**, No. 4, 50-53 (1955).

A discussion of some of the problems which arise in 1) hot-dip galvanizing-due to carbon, Fe_3C, silicon and oxide inclusions on the surface of iron and steel articles; 2) chemical and electrochemical pickling and plating processes —due to hydrogen evolution, e.g. the formation of hair cracks and porosity in hard chromium deposits; 3) surface-diffusion processes—of carbon, chromium and nitrogen in iron and steel; 4) the formation of passive films by chemical and electrochemical processes, e.g. phosphatizing and anodizing; and 5) forming processes.—MA. 11899

5.4 Non-Metallic Coatings and Paints

5.4.2

The Vitreous Enamel Finish. A. W. MURDOCH. *Paint, Oil and Color Jr.*, **127**, No. 2956, 1470-1473 (1955) June 10.

A paper containing a general account of the history, formulation and uses of vitreous enamels. Basically the enamels are borosilicates of sodium, potassium, calcium and aluminum and sometimes also zinc and barium.—ZDA. 11890

5.4.5

Epoxy Resin Finishes. P. A. DUNN. *Electroplating & Metal Finishing*, **8**, No. 3, 107-112 (1955) March.

Chemistry of epoxy resins and use of coatings based on epoxy resins in combination with urea, melamine and phenolic resins are given. Air drying and stoving finishes based on epoxy resins treated by esterification with carboxylic acids, styrenation and reaction with amines or amine adducts and applications of the various coating systems are discussed.—BL. 11774

5.4.5

Development of Protective Waxes. Schliemann's Export-Ceresin-Fabrik. *Deut. Farben-Z.*, **9**, No. 8, 303-306 (1955).

Wax coatings for temporary protection of metal articles are reviewed. —RPI. 11768

5.4.5

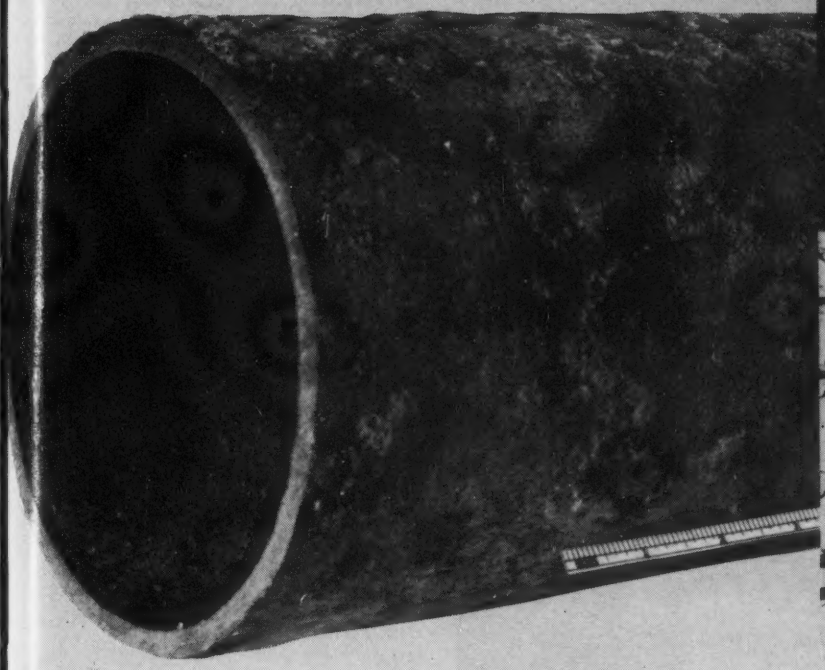
Sodium Benzoate and Benzoic Acid in the Paint Industry. Pamphlet, 1955, 9 pp. Monsanto Chemicals, Ltd., St. Louis, Missouri; *Paint J.*, **4**, No. 27, 233, 239, 274 (1955).

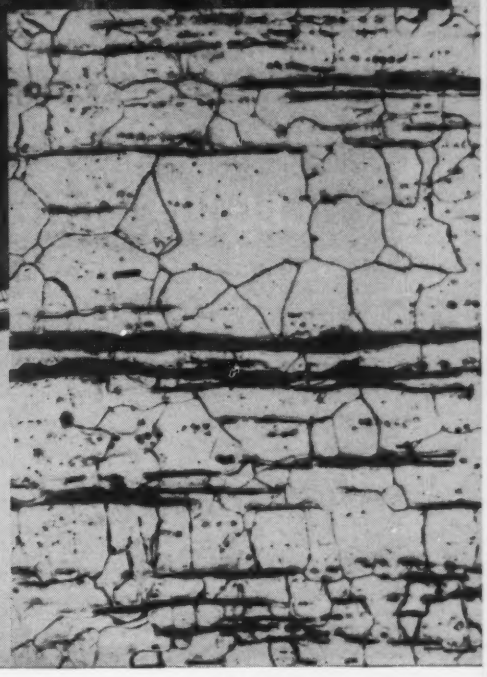
In many emulsion and water paints an addition of 0.5-2% sodium benzoate based on the wt. of paint is effective in combating can corrosion; it is also normally beneficial to add 0.1-0.2% so-

nother Wrought Iron case against corrosion

56

YEARS OF SERVICE





Photomicrograph U-85-3 shows a typical area of the microstructure observed in the subject 5-inch wrought iron pipe.

Metallurgical Report 2187—Underground Oil Line*

This report deals with the metallurgical examination of a length of 5-inch wrought iron pipe, approximately two feet (2') long, submitted to our laboratory for investigation and comment.

General condition of the as-received sample is shown in large photograph above. Outer surface displayed some few shallow corroded areas but was otherwise in good condition. Inner surface of the pipe sample was also in excellent condition.

ROCKWELL HARDNESS

A cross-sectional ring was prepared for hardness determinations. Hardness values, taken around the cross-sectional ring indicated a B67 hardness typical for wrought iron pipe and in lieu of tensile properties showed that the strength and ductility were likewise normal.

CHEMICAL ANALYSIS

Carbon—.025%; Manganese—.066%; Phosphorus—.230%; Sulphur—.020%; Silicon—.120%; Iron Silicate—2.82%.

SUMMARY

Results of the laboratory examination serve as positive identification of the subject sample as wrought iron. The excellent condition of this sample after more than fifty years of service is noteworthy. This report offers documentary evidence of wrought iron's corrosion control in undergound service. A. M. Byers Company, Clark Building, Pittsburgh 22, Pa.

*Name of actual installation given on request.

Write for free cloth-bound book, "Wrought Iron: Its Manufacture, Characteristics and Applications."

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dium nitrite, particularly in paint of a slightly acidic nature. Polyvinyl acetate emulsion paints tend to become acid on storage and in this case both inhibitors need to be used. Corrosion of metal surfaces such as nail heads, after application, is also inhibited by the above additions. Benzoic acid (4½-9% on the wt. of phthalic anhydride) can be used with advantage in the manufacture of alkyd resins. This prevents the condensation reaction from proceeding too far and gives the dried film greater flexibility. Benzoic acid in small quantities (0.2-0.5% on the total paint) as an additive to the finished paint improves flow properties and coverage and helps to prevent darkening in baking enamels. —RPI. 11761

5.4.5

Amino Resins in Modern Industrial Finishes. H. T. CHELLINGSWORTH. *Electroplating & Metal Finishing,* **8,** No. 8, 287-292 (1955) August.

Chemistry of amino resins and progress made in development and utilization in surface coatings. Amino alkyd and amino epoxy resin coatings, applications of epoxy resin coatings, cold setting urea-alkyd coatings, miscellaneous amino coatings and choice of amino resin are discussed. Bibliography.—BL 11792

5.4.5, 7.7, 7.2

Corrosion Control Practices for Pipe-Type Cables on the Detroit Edison System. W. A. SINCLAIR. *Corrosion,* **12,** No. 8, 385t-388t (1956) August.

A description is given of the procedure followed in protecting the pipe of buried pipe-type cables. The first step in protecting such pipes was to see that a ½-inch thick coating of Somastic was applied. After the pipes had been coated and installed, a 500 volt megger was used to determine whether or not the required 10 megohms per square foot of pipe surface resistance had been attained. When irregularities were detected in a section, an interrupted direct current was applied between the ground and pipe and a ground survey was made.

A discussion is given of factors involved in the field application of Somastic to pipe welds. It was found that cracking could be minimized by keeping the temperature in the mechanical mixer between 300 and 350F.

A corrosion problem was created when several hundred gallons of a cleaning fluid were lost in the ground adjacent to a manhole in the cable line area. It was decided this solvent could be kept out by treating the concrete walls of the manhole with a Thiokol latex solution. In addition a Thiokol base material was used as a coating for the Somastic-coated pipe in the saturated area. When the pipe was inspected six years later it was found there had been no disintegration of the covering. 11877

5.4.5

The Painting of Structural Steelwork: Third Interim Report. *Paint Technology,* **20,** 15-17 (1956) Jan.

Litharge and lead linoleate have little effect on the life of red oxide and linseed oil primers. Photographs, table.—BTR. 11608

5.4.5

Paint Faults and Remedies. Part XVII. H. COURTNEY BRYSON. *Corrosion Prevention and Control,* **3,** 40-42 (1956) February.

Causes and preventive measures for precipitation, rain-spotting, ropiness, sagging and other defects. Photographs. (To be continued.)—BTR. 11556

5.4.5, 5.4.10, 2.2.5

New Developments in Tests of Coatings and Wrappings. GRAYDON E. BURNETT AND PAUL W. LEWIS. *J. Am. Water Works Assoc.,* **48,** 100-120 (1956) Feb.

Laboratory and field tests of protective coatings and wrappings for steel water pipe conducted by the Bureau of Reclamation. Coatings tested were proprietary products and have been in service up to five years. Tables, photographs. 4 references.—BTR. 11576

5.4.5, 5.9.4

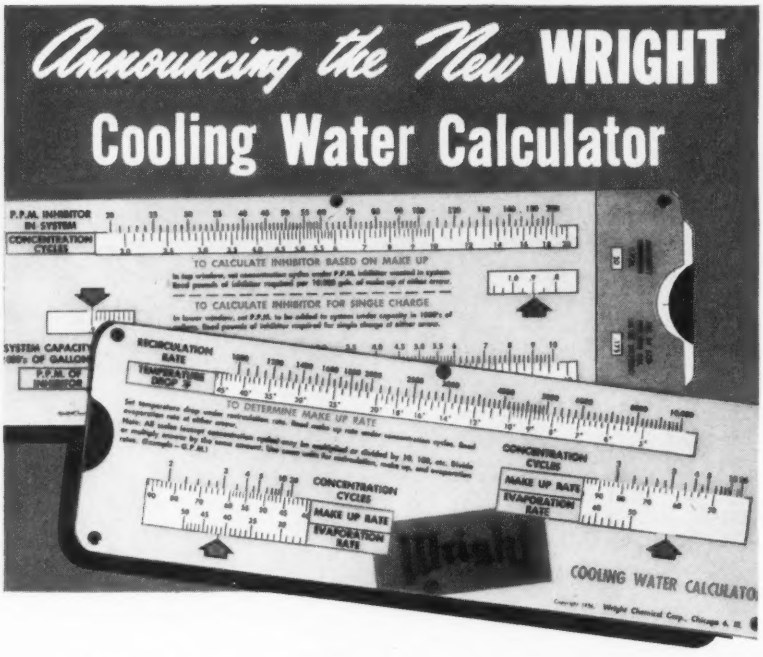
Processes Occurring at the Interface Between Films and Metal Surfaces. B. WASER. *Deut. Farben Z.,* **9,** No. 8, 296-301 (1955).

Methods of determining the reactivity of metal surfaces were discussed, reference being made to phosphate treatment, linseed oil/red lead paint and phosphoric acid/polyvinyl butyral/zinc chrome wash primers and the general theories of the action of wash primers.—RPI. 11896

5.4.5, 8.5.3

Selection and Application of Coatings in the Pulp and Paper Industry. RAYMOND B. SEYMOUR. *Corrosion,* **12,** No. 8, 406t-410t (1956) Aug.

Practical information is given on the selection and use of protective coatings in the pulp and paper industry. The main points to be considered in the selection of any coating are relative resistance of the product to the environment, ease of application, experience



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under similar conditions of exposure, cost per year of the applied coating and choice of colors. Information of this kind is given for the following materials: Chlorinated rubber, vinyl, liquid Neoprene, epoxy-amine, asphaltic mastic and oil base paints. Also included is information concerning the resistance of these coatings to a number of acids, alkalies, acid salts, alkaline salts, neutral salts, gases and organic materials.

The importance of good surface preparation is discussed. Recommendations are made concerning the application of coatings. Properties of specific coating materials are given and typical specifications listed. 11889

5.4.6

Necessary Number of Coats for an Effective Rust-Protective System. H. RABATE. *Trav. Peintures,* **10,** No. 12, 465-466 (1955).

A review of the literature and practical experience, establishes that for normal exposure conditions a minimum film thickness of 125 μ is necessary on steel and that for severe exposure conditions the figure should be 150μ.—RPI. 11860

5.5 Oil and Grease Coatings

5.5.3

Protective Oil Coatings. K. F. SCHIERMEIER AND R. W. LEWIS. *Lubrication Eng.,* **12,** 19-23 (1956) Jan./Feb.

Types of protective films and factors influencing selection of proper type. Basic considerations in the formulation of rust preventives. Table, graph, 1 reference.—BTR. 11652

5.5.3, 5.8.2

The Effect of Purification of Commercial Sulfonates on Their Corrosion-Stain Property. HARRY C. MUFFLEY, VAN HONG AND DAVID BOOTZIN. *Corrosion,* **12,** No. 8, 411t-414t (1956) August.

Sulfonates are used to a great extent in the preparation of corrosion preventive lubricating oils. Investigations were conducted to determine whether the staining characteristics of commercial sulfonates could be eliminated by purification and to identify the material causing the stain.

An extraction procedure produced a sulfonate that caused less staining than the original commercial sulfonate. The materials causing the stain were water soluble sulfonates and inorganic salts. 11892

5.6 Packaging

5.6.3

Corrosion of Cutlery in Contact with Packing Material. E. A. OLDFIELD. *British Paper and Board Makers' Association, Proceedings of the Technical Section,* **36,** Pt. 3, 509-522; disc., 523-534 (1955) Dec.

Cutlery stainless steel can be corroded by high chloride content paper and board. Additional protection can be supplied to metal goods by the use of desiccating containers, inhibitors or films of plastic and petroleum derivatives. Diagrams, photographs. 11 references.—MA. 11854

5.9 Surface Treatment

5.9.2

Cleanability and Oil Spreading Rates: Am. Electroplaters' Soc. Research Project No. 12. H. B. LINFORD AND P. E. GRUBB. *Plating,* **42,** No. 7, 895-902 (1955) July.

Investigation for developing correlation between spreading rate of various oils, fats and greases on particular metal with cleanability or difficulty of cleaning that soil from another metal. Oils included micro crystalline wax, stearic acid and crude scale wax.—BL. 11842

5.9.2, 6.3.15

Sodium Hydride Descaling of Titanium. Q. DE L. WHEATLEY. *Metal Progress,* **68,** No. 2, 114-116, 119 (1955) Aug.

By adding titanium dioxide to the hydride bath, absorption of hydrogen is decreased. 11786

5.9.2, 6.3.15

Hydrogen Contamination of Titanium Minimised by Modified Descaling Bath. H. L. ALEXANDER, H. FARRELL AND Q. D. WHEATLEY. *Metal Progress,* **69,** No. 2, 78-80 (1956) Feb.

Saturation of sodium hydride baths with titanium dioxide minimizes hydrogen pickup during descaling of titanium. The coarser grades of titanium dioxide should be used and added slowly to avoid excessive foaming and gas evolution.—BNF. 11866

5.9.2, 8.8.5

Pickling Processes Reviewed. Part I. Choice of Reagent. Part II. Choice of

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31a

Plant. D. J. FISHLOCK. *Product Finishing,* **8,** No. 11, 61-71, 110; 52-68, 104 (1955) Nov., Dec. In Progress.

I. Various reagents in use are considered including tables on choice of pickling method for removal of particular contaminants or treatment of different surface conditions (e.g., removal of moulding sand, scale, graphite, metal dust, cleaning deep recesses, highly polished or embossed surfaces, etc.) and choice of method for different metals (steels, copper and alloys, zinc, tin, lead, aluminum, magnesium, nickel, titanium and cast iron); salt bath descaling; rinsing practice. II. Plant floors, fume extraction, pumps, heating; use of plastic material (with table showing resistances to various acids); acid resistant brick; acid recovery methods; waste disposal. —BNF. 11827

5.9.3

Using Blast Cleaning Techniques for Cleaning and Finishing. E. F. ANDERSON. *Plating,* **43,** No. 1, 82-86 (1956) Jan.

Dry and wet blasting, their advantages and applications are covered.—BL. 11924

5.9.3, 1.6

Handbook of Barrel Finishing. R. ENYEDY. Book, 1955, 253 pp. Reinhold Publishing Corp., New York; Chapman & Hall, Ltd., London.

After covering briefly types of barrels available and the finishing compounds and media used with them, details the operations to which they are applicable. Numerous data sheets giving examples of detailed procedure for finishing a very wide variety of shapes and sizes of components. Uses of modern multi-barrels and triple action barrels are described. —BNF. 11776

5.9.4

Factors Affecting the Formation of Anodic Oxide Coatings in Sulphuric Acid Electrolytes. R. B. MASON. *J. Electrochem. Soc.,* **102,** No. 12, 671-675 (1955) Dec.

The amount of sulfate in anodic coatings on pure aluminum increased with increasing current density and acid concentration and with decreasing temperature. The mechanism of pore formation and factors affecting the solubility of the coating were also studied.—BNF. 11772

5.9.4

Anodic Oxide Films. Part IV. The Interpretation of Impedance Measurements on Oxide-Coated Electrodes on Columbium. LAWRENCE YOUNG. *Trans. Faraday Soc.,* **51,** No. 9, 1250-1260 (1955).

Cf. *ibid.,* **50,** 153, 159, 164 (1954). Measurements of the impedance I of niobium electrodes are reported as a function of frequency f and thickness d of the oxide for films formed in sodium sulfate and sulfuric acid solutions. I is represented by a capacity C and a resistance R in series. Typically, $R \propto d/f$. C^{-1} is linearly dependent on log f. These results can be explained if the resistivity ρ of the oxide varies exponentially with distance through the oxide. $dC^{-1}/d \log f$ tends to be independent of d. This can be explained if ρ at the inner and outer faces is independent of d. These assumptions appear consistent with the conductivity being due to non-stoichiometry, the degree of which at the interfaces is controlled by local equilibria. The behavior, except for very thin films, cannot be due to the dependence on f of the I of the electrical double layer at the oxide/solution interface. Preliminary investigations show similar behavior under certain conditions for aluminum, zirconium and tantalum. 12 references.—MA. 11879

5.9.4

Mechanical Properties and Wear Resistance of Gas Cyanided Auto Parts. A. M. TARASOV AND B. A. STETSENKO. *Avtomobil. i Traktor. Prom.,* No. 3, 21-24 (1955).

Comparative case depths, case and core hardnesses, transverse rupture strengths, fatigue strength and wear resistance of teeth of various types of gears for gear-boxes and rear axles of two different types of automobile. Steel compositions selected include 40KhS (0.38-0.43 carbon, 0.50-0.80 manganese, 0.17-0.37 silicon, 0.80-1.10 chromium, max. 0.04 phosphorus, max. 0.04 sulfur), steel with 0.15-0.25 carbon, 0.40-0.70 manganese, 0.17-0.37 silicon, 0.45-0.75 chromium, 1-1.50 nickel; and 38 KhMYuA (0.38 carbon, 0.3-0.6 manganese, 0.5 nickel, 1.45 chromium, 0.5 molybdenum, 1 aluminum). Results obtained with dry cyaniding are compared with liquid cyaniding. Metallographic examination was made of gears studied. Selection of furnaces for dry cyaniding, pit type vs horizontal type and experience gained in their operation are discussed.—INCO. 11845

5.9.4

Electrolytic Processes for Surface Conditioning of Metals. J. W. CUTHBERTSON. *Proc. Inst. Elec. Engineers,* **102,** No. 5, Part A, 501-599 (1955) October.

Use of electrolysis for surface cleaning and descaling of metals (cathodic cleaning, anodic pickling in acid electrolytes, etc.); improving corrosion and abrasion resistance of aluminum and aluminum alloys (theory and practice of anodizing, application in photography, modified procedure for abrasion- and wear-resistant surfaces); electrolytic polishing (methods for steel, nickel, copper and aluminum), comparison of electrolytic and mechanical polishing, economics. 29 references.—BNF. 11778

5.9.4, 6.2.5

Effect of Deformation on Chemical Brightening of Austenitic Chromium-Nickel Steels. (In German.) A. VON KRUSENSTJERN AND H. SCHLEGEL. *Metalloberflache,* Sec. B, **9,** No. 10, 148B-152B (1955) Oct.

Effect of working and roughening (polishing paper) on brightening in a bath of phosphoric acid/hydrochloric acid/nitric acid/water. Photomicrography and measurement of lustre with a small simple apparatus. Deep drawing, annealing and pickling all cause macro-roughening beyond the limit at which they can be obviated by chemical polishing. —BNF. 11871

5.9.4, 6.3.19

A Surface Structure Observed on Electrolytically Polished Zinc. K. F. HULME. *Acta Metallurgica,* **3,** No. 6, 572-578 (1955) Nov.

A structure produced on zinc by electrolytic polishing in 20% aqueous CrO_3 solution (similar to structures produced by others on aluminum and copper) is thought to be associated with the electropolishing process rather than the internal structure or "mosaic" of the metal. An explanation is given which has relevance to the theory of electropolishing.—BNF. 11738

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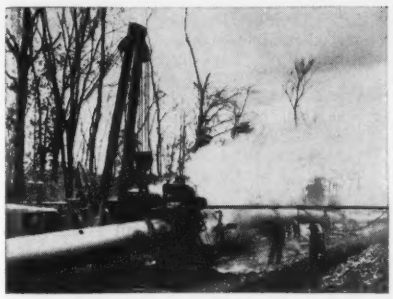
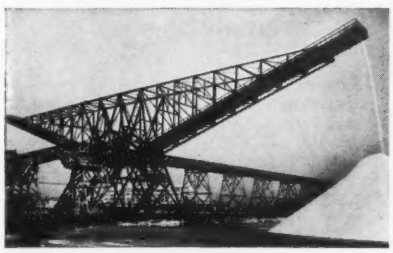
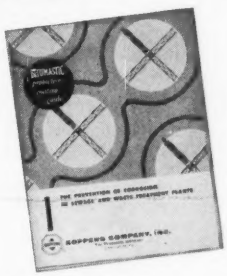


American Louisiana Pipeline, carrying natural gas 1000 miles from Louisiana to Michigan, was given the proven protection of coal-tar enamel coatings. Three different types of enamels were used on various sections: Bitumastic® No. 2 Enamel for application in mild climates, Bitumastic No. 70-B Enamel for application to portions subjected to colder weather, and Bitumastic Hi-Melt Enamel for hot sections of the line after compressor stations. There's a Bitumastic Enamel for every pipeline need, from hot-line coating to sub-zero conditions. Your Koppers representative will be glad to explain why coal-tar enamel is your best investment for long-lasting protection of pipelines.



19 Years of Protection were given this giant gantry crane at a salt-producing plant by a coating system of Bitumastic Super Service Black. Exposed to the corrosive combination of salt plus atmospheric moisture, the coating system has required only minor touch-up in all these years of service. Bitumastic Super Service Black is one of seven Bitumastic coatings; the complete line offers wide flexibility in the selection of corrosion-preventive materials to best meet the individual requirements of your application.



Corrosion Control in sewage and waste treatment plants is the subject of a new bulletin now available from Koppers. It contains complete engineering specifications for protective coating systems. Please request your copy on company letterhead from Koppers Company, Inc., Tar Products Division, 1455 Koppers Building, Dept. 100B, Pittsburgh 19, Pa.

how to CUT CORROSION LOSSES

a report by Koppers Company, Inc.

Number 8 of a series

F. R. Charlton
Development Group Supervisor

An ideal coating possesses the ability to adhere tenaciously to a metal surface directly. Coal-tar enamels will provide such a bond when the surface is preheated. However, enamels applied directly to metal surfaces at normal temperatures chill too quickly and a poor bond results.

* * *

To overcome this problem, enamel primers of modified coal-tar pitch in suitable solvents were developed. When hot enamel is applied over a thoroughly dry, solvent-free pitch film, the primer melts slightly and produces a welded system—primer to pipe and enamel to primer.

The drying time of enamel primers is directly related to the volatility of the solvent and the environment. If hot enamel is applied to the primer before it is completely dry, the traces of solvent will destroy the bond to the enamel. Conventional practice is to prime one day and enamel the next, although this waiting period may be extended to several days or longer by poor drying conditions.

* * *

The Coatings Group at our Verona Development Laboratory recently studied this problem from a fresh point of view. They searched for a new base material, other than coal-tar pitch, which (1) would be compatible with the enamels, (2) would permit employing more volatile solvents, and (3) would provide a superior bond. After thorough study, a number of new formulations were tested. One met the requirements; it is called Bitumastic® Jet-Set.

Bitumastic Jet-Set is an entirely new kind of primer. It is formulated from special, plasticized resins which permit the use of low-boiling solvents and are compatible with coal-tar enamel. Bitumastic Jet-Set exhibits remarkably low temperature susceptibility and excellent resistance to chemical environments and moisture.

The drying rate of Bitumastic Jet-Set is truly amazing. It dries to touch in from 1 to 15 minutes and is ready for enameling in a maximum of 8 hours; conventional primers under similar conditions require several days to dry adequately.

* * *

Bitumastic Jet-Set opens up entirely new opportunities for the application of coal-tar enamel. Field experience has proved that the fast-drying characteristic of this new primer saves time and actually permits work to continue where heretofore, conventional primers have necessitated shutdown. Another application, where piling was driven after being enameled, demonstrated the excellent bonding ability of Bitumastic Jet-Set.

Complete data on this new primer is available. Ask your local Koppers representative, or write Koppers Company, Inc., 1450 Koppers Building, Department 100B, Pittsburgh 19, Pa. District Offices: Boston, Chicago, Los Angeles, New York, Pittsburgh, and Woodward, Ala. In Canada: Koppers Products, Ltd., Toronto, Ont., and Edmonton, Alta.

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COATINGS AND ENAMELS

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.1, 3.2.3

The Dry Oxidation of Iron and Steel. (In French.) LUCIA DE BROUCKERE AND MADELEINE MATHYS-SOLVEL. *Ind. chim. belge,* **20,** No. 1, 35-53 (1955) January.

Studies of iron and of mild steel exposed to pure air between 200 and 900C. Micrographs, graphs, tables. 10 references. —BTR. 11430

6.2.1, 5.1, 1.6

Rust Damage and Protection Against Rust. (In German.) BRUNO WAESER. Book, 1956, 247 pp. Wilhelm Pansegrau Verlag, Uhlandstrasse 102, Berlin-Wilmersdorf, Germany.

Theoretical and practical considerations involved in the protection of iron against rust are discussed. Sections cover theory, German patent literature, protection by organic and inorganic coatings, cathodic protection, characteristics of different kinds of iron alloys and testing methods. There are extensive references after each section and alphabetical subjects and author indexes. 11667

6.2.2

A Contribution to the Study of the Effects of Gas on the Structure of Cast Iron. G. BLANC AND N. VOLIANIK. *Fonderie,* No. 118, 4755-4770 (1955).

Cast iron containing 2.9-3.7 carbon, 1.7-2.5 silicon, 0.3-0.6 manganese, 0.06-0.12 sulfur, 0.07-0.23 phosphorus, balance iron was melted under reducing conditions; exposed to air, hydrogen, oxygen and to nitrogen; treated with iron-silicon, calcium-silicon, iron oxide (mill scale), or iron-silicon-magnesium; and cast into ½-inch and ⅞-inch diameter test ingots for study of chemical composition, tensile properties, macrostructures and microstructures. Prolonged exposure of the uncovered molten bath to air and treatment with mill scale did not affect castability or chemical composition appreciably; iron-silicon and calcium-silicon reduced oxygen content of the iron and iron-silicon-magnesium produced spheroidal graphite iron and decreased oxygen and nitrogen contents. Further study of the form in which oxygen, nitrogen and hydrogen occur in the iron is indicated. Bibliography.—INCO. 11701

6.2.2, 1.6

Wrought Iron. JAMES ASTON AND EDWARD B. STORY. Book, Third Edition, 1956, 102 pp. A. M. Byers Co., Pittsburgh, Pa.

A comprehensive exposition of wrought iron materials. Chemical and structural characteristics are followed by a brief history of wrought iron production prior to 1850. Modern developments in production are discussed as are quality standards, specifications for durability testing, methods of working, fastening and welding and principal applications.

In the chapter devoted to characteristics the resistance to corrosion of wrought iron is laid to the character of the layer of corrosion products formed on the surface, the effect of the slag fibers and its ability to form a firm bond with metallic and organic coatings. 11571

6.2.2, 5.3.4

Physico-Chemical Conditions of Diffusion Film Formation on the Surface of Iron and Its Alloys. (In Russian.) N. S. GORBUNOV. *Bull. Acad. Sci. USSR* (Izvest. Akad. Nauk), No. 5, 793-799 (1955) Sept.-Oct.

The process of diffusion film formation on iron and its alloys was studied with the groups and subgroups of Mendeleev's periodic system. The similarity of crystal lattices of the film element and iron, the comparatively smaller atomic diameter of diffusing elements and the sufficient solubility of it in iron at room temperatures are the conditions causing the formation of diffusion films on iron and its alloys.—NSA. 11478

6.2.3

The Protection of Structural Steel. Principles of Protective Painting. G. DECHAUX *Chemistry & Industry,* No. 48, 1535-1541 (1955) November 26.

Corrosion of metal structures exposed to the weather and sea water; comparison of polished unpainted steel, rough unpainted steel and painted steel, formulation and appraisal of the efficiency of anticorrosive paints. Diagram, graphs, micrographs. 12 references.—BTR. 11456

6.2.3, 6.2.4, 6.2.5, 1.6

Steels for the User. R. T. ROLFE. Book (3rd. Ed.), 1955, 399 pp. Chapman and Hall Ltd., London.

In this new edition (the second was issued in 1942) there have been extensive deletions and additions. In the main, the book deals with carbon steels, but alloy steels are discussed for special duties, e. g., high-temperature service. Chapters include composition and mechanical properties, bright and free-cutting steels, heat treatment, case hardening, use at high temperatures, fatigue testing, weld testing, general principles of selection.—BNF. 11915

6.2.3

The Protection of Structural Steel. J. BIGOS. *Chemistry and Industry,* No. 47, 1503-1510 (1955) Nov. 19.

Provided a building structure is kept watertight, it is unnecessary to paint the steel to protect it from corrosion. Paint systems are recommended for steelwork on the inside of a building and for weather-exposed steel. Alkyd and zinc dust primers are recommended in some of the former cases, while vinyl paint systems show promise on steel immersed in water.—ZDA. 11714

6.2.3, 8.8.1, 1.2.2

The Protection of Structural Steel. The Protection of Steelwork in Chemical Factories. F. R. HIMSWORTH. *Chemistry & Industry,* No. 50, 1618-1622 (1955) December 10.

Consider painting, sprayed metal coatings and other forms of protection and economic considerations involved. Table.—MR. 11546

6.2.4, 6.2.2, 6.2.3

Corrosion Resistance of Low Alloy Steels. J. A. POPE AND A. K. MOHAMED. *J. Iron Steel Inst.,* **180,** 271-284 (1955) July.

Low-alloy additions are a valuable means of reducing the rusting of steel exposed to the atmosphere outdoors. Under these circumstances the most resistant low-alloy steels rust during the first year or two of exposure at only one-third the rate of unalloyed mild steel. With longer exposure, they appear to still greater advantage. The most useful alloying elements for this purpose are chromium, copper and nickel. Aluminum and beryllium may also be of value. Otherwise, none of the wide variety of alloying elements tested was found to have had a marked effect on the resistance of steel to atmospheric corrosion. When immersed in sea-water low-alloy steels show to less advantage, but, under the more or less stagnant conditions described in the paper, the addition of about 3 percent of chromium to mild steel roughly halved its wastage by corrosion over five years. The corrosion rates of plain carbon steels, over periods of several years in air or in sea water, are not markedly influenced by differences in their carbon contents. The results indicate that high-carbon steels are less corrodible in the atmosphere than low-carbon steels but more so in the sea. The differences are not great, however, and are about 20 percent in both cases. Heat-treatment is not a major factor in determining the severity of corrosion of low-alloy steels over long periods of exposure to air and sea water, but it may have a pronounced influence in laboratory tests extending over a few weeks only. There is little difference in the general corrosion of cast irons and plain carbon steels when immersed in sea water, although the former may be seriously weakened by local attack and graphitization. No general conclusion about the respective merits of the two types of material when exposed to the atmosphere can be drawn from this investigation. Laboratory tests of the intermittent spray type yield only fair correlation with the results of outdoor exposure. This is probably because the rusting of the steels in the laboratory test does not proceed sufficiently far for the differences in the properties of the rusts on the various steels to become fully operative. The investigation has demonstrated conclusively that marked improvements in the corrosion resistance of structural steels can be brought about by small additions of suitable alloying elements. This is particularly true for atmospheric exposure.—TIME. 11550

6.2.5

Corrosion Resistance and Mechanical Properties of Chromium-Nickel-Manganese Stainless Steels. R. A. LULA AND W. G. RENSHAW. *Metal Progress,* **69,** No. 2, 73-77 (1956) Feb.

Discusses properties of AISI Types 201, 202, 204 and 204L and an experimental grade designated 20-6-8, which make them suitable for many structural applications in corrosive environments. Austenitizing influence of nickel and manganese is not adequate and must be supplemented by nitrogen additions. Tensile properties of Types 201 and 202 are compared with those of 301 and 302. Magnetic permeability of cold worked stainless steels is shown graphically. Graphs show the effects of chromium, nickel, manganese and carbon contents on corrosion rate in 65% nitric acid. With short-time sensitizing, the chromium-nickel-manganese steels are less susceptible to intergranular corrosion than Type 304 of equal carbon content. Types 201 and 202 may replace 301 and 302 in many corrosive environments. Under severe conditions, experimental steel 20-6-8 appears satisfactory. Graphs. —INCO. 11607

6.2.5, 1.6

The Metallurgy of the Chromium-Nickel Austenitic Steels. F. H. KEATING.

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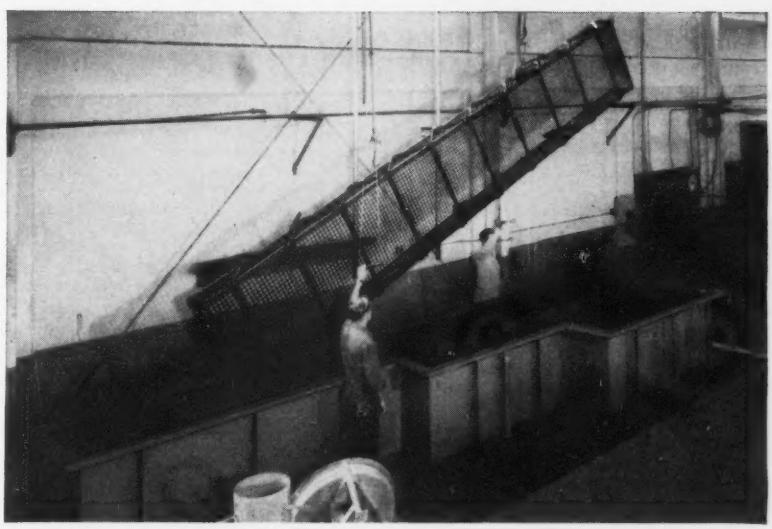

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Unichrome Plastisols can be applied by all the other usual methods, too, including *spraying*. They're limited only by the facilities available to heat and hold the coated object at 350° to 365°F for curing. Send for Bulletin VP-1.

35a

Book, 1956, 138 pp. Butterworths Scientific Publications, London.

Metallurgy and development, manufacturing and fabricating processes and casting of chromium-nickel austenitic steels are described. Discussion of mechanical, physical and corrosion properties of austenitic steels is presented. A chemical analysis of chromium-nickel austenitic steels is given.—INCO. 11606

6.2.5, 3.2.2

Selective Corrosion of Delta Ferrite in Cast Stainless Steel: Topic of the Month. J. M. Bialosky. *Corrosion,* **12,** No. 2, 59t (1956) February.

Corrosion of Type 304 shaft and vane and CF8 hub and body castings of a Simplex Dispersator operated in mixture of organic liquid and water during neutralization of an acid catalyst with caustic soda. Type 304 exhibited corrosion rates of 0.001 and 0.002 ipy with no pitting or localized attack. Metallographic specimens of body casting show delta ferrite structure which was preferentially attacked and resulted in deep pits. Nickel content on high side of allowable range for casting is recommended to minimize amount of delta ferrite. Photomicrograph.—INCO. 11564

6.2.5, 3.5.8, 4.6.1

Stress Corrosion of Austenitic Stainless Steels in High Temperature Waters. W. L. Williams and J. F. Eckel. Selected information from chapter on stress corrosion in "Wear and Corrosion Handbook for Water Cooled Reactors" being prepared on Navy Contract by Westinghouse Elec. Corp., Atomic Power Div. *J. Am. Soc. Naval Engrs.,* **68,** No. 1, 93-104 (1956) Feb.

Results of extensive laboratory test program on stress corrosion of austenitic stainless steels in high temperature water and steam including brief description of procedure, conclusions reached and illustrative data only as needed for clarity. Following literature review, results of tests of small laboratory specimens and of small boilers made of welded Type 304 are discussed. Numerous tests were conducted in alkaline-phosphate treated waters. Cracks were predominantly transgranular. Use of annealed steels, stress relief treatments, stabilized grades, low operational stresses, low chloride levels, low oxygen levels and proper corrosion inhibitors are all important steps toward elimination of stress corrosion hazards. Photomicrographs of stress corrosion cracks are included. Graphs, table, 28 references.—INCO. 11659

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.2, 3.8.2

Electrochemical Behavior of Cadmium in Acid Solutions of Electrolytes. Influence of Haloid Potassium Salt Additions. (In Russian.) Ia. M. Kolotyrkin and L. A. Medvedeva. *J. Phys. Chem., USSR* (Zhur. Fiz. Khim.), **29,** No. 8, 1477-1485 (1955) August.

Relation of cadmium solubility to concentration of potassium iodide in sulfuric acid solution. Cathode and anode polarization curves. Graphs, tables. 18 references.—BTR. 11448

6.3.3, 3.5.8, 3.8.4

The Fracture of Brittle Chromium by Acid Etching. W. H. Smith. *J. Electrochem. Soc.,* **103,** No. 1, 51-53 (1956) Jan.

Mechanism explains formation of transcrystalline cleavage cracks during etching of brittle annealed chromium. Formation of a face-centered-cubic chromium hydride on the surface initiates cracks in brittle metal beneath due to its larger volume. Cracks propagate by a stress corrosion mechanism. Room temperature ductile chromium takes up this volume expansion without cracks being initiated. Photomacrographs.—INCO. 11371

6.3.6, 3.5.8

Electrochemical Behavior of Copper-Gold Alloy and the Mechanism of Stress Corrosion. (In German.) Heinz Gerischer and Hans Rickert. *Z. Metallkunde,* **46,** No. 9, 681-689 (1955) Sept.

Current density curve of the alloy; influence of mechanical load; stress corrosion under anodic current; localization of corrosion. Graphs, diagrams, table. 13 references.—BTR. 11414

6.3.6, 3.7.4, 3.2.2

Effect of Grain Boundaries Upon Pore Formation and Dimensional Changes During Diffusion. R. W. Balluffi and L. L. Seigle. *Acta Metallurgica,* **3,** No. 2, 170-177 (1955) March.

The effects of grain boundaries and specimen thickness upon pore formation and dimensional changes which occur when zinc is diffused out of polycrystalline alpha brass sheets have been studied. The results are consistent with the hypothesis that the outward flux of zinc produces a supersaturation of vacancies which may either precipitate as pores or else be absorbed at sinks within the alloy, causing various dimensional changes.—ZDA. 11295

6.3.6, 4.6.6

Corrosion of Brass by Chloramine. T. E. Larson, R. M. King and L. Henley. *J. Am. Water Works Assoc.,* **48,** 84-90 (1956) January.

Faucet seats of Monel metal or electrolytically silver-plated brass gave good service, resisting corrosion by chloramine in the water supply. Tables. 5 references.—BTR. 11304

6.3.6

Surface Finish of Brass Strip. (In German.) F. Deutz. *Z. Metallkunde,* **46,** No. 4, 254-263 (1955) April.

Methods of attaining clean surfaces on brass strip. Removal of surface skin after casting and rolling, continuous annealing, degreasing, pickling, washing, annealing in protective atmosphere.—BNF. 10540

6.3.6

Contribution to the Chemical Study of the Corrosion of Copper in Sodium Chloride Solution. (In French.) W. Feitknecht and W. Schutz. *Rev. met.,* **52, No. 4,** 326-334 (1955) April.

Specimens prepared by electropolishing and light attack by nitric acid. Rate of corrosion in sodium chloride solution by loss of weight after dissolution of solid corrosion products; pH control by glass electrode; structure of corrosion products by electron and X-ray diffraction; morphology by electron microscopy.—BNF. 10514

6.3.6, 2.2.2

Effect of Natural Atmospheres on Copper Alloys: 20-Year Test. A. W. Tracy. American Society for Testing Materials, Preprint No. 91b, 1955, 10 pp.

Corrosion resistance of 11 copper alloys exposed to industrial, marine, and rural atmospheres over a period of 20 years. Evaluation is based on weight-loss measurements and changes in mechanical properties of sheet specimens. Tables, graphs. 7 references.—BTR. 10356

6.3.6, 3.5.8

The Stress Corrosion of Brass and Its Prevention by Silicon. (In German.) H. Steinle. *Metall,* **9,** No. 11/12, 492-495 (1955) June.

Effect of silicon content and degree of cold working on susceptibility to stress corrosion and hardness of brasses. Photographs, graphs, micrographs, tables.—BTR. 10352

6.3.6, 3.5.8, 3.7.4

Investigations into the Stress-Corrosion of Alpha Brass in Ammonia Vapour. Part I: Statistical Investigations on the Effect of Structure on the Durability of Annular Test Specimens. F. Aebi. *Z. Metallkunde,* **46,** 547-551 (1955) Aug.

Statistical evaluation of stress-corrosion tests made on α-brass exposed to ammonia vapor showed that specimens which had not been heat-treated after forming and hence retained their original structure, had higher life than those heat-treated for four hours at 300 degrees. The shorter life of the heat-treated specimens is explained by the dislocations produced by polygonizations offering additional points of attack for intercrystalline crack formation.—INCO. 10460

6.3.6, 3.7.3

Aluminum Bronze Alloys. N. C. Ashton and C. V. Wilson. *Metal Ind.,* **87,** Nos. 8, 9, 145-146, 149; 165-168 (1955) August 19, August 26.

Discusses progress made in the development of aluminum bronzes for deep drawing dies, particularly for difficult materials and for turbine and other applications. The effect of alloy additions of iron and nickel on the phase transformation of copper-aluminum system are considered. Nickel tends to strengthen both the alpha and beta solid solutions and to improve ductility in the heat-treated condition. Data are presented for effect of heat treatment and working on mechanical properties, tensile properties at sub-normal and elevated temperatures (—182 to 538C), creep, fatigue and corrosion fatigue for aluminum bronzes with 4.56-5.5 percent nickel. Tables.—INCO. 10463

6.3.6, 3.2.3, 3.7.3

The Oxidation of Copper Sheet at 400C. K. Lohberg and F. Wolstein. *Z. Metallkunde,* **46,** 734-737 (1955) Oct.

Oxidation tests on high-purity electrolytic copper sheet showed marked relationship between degree of cold rolling and rate of oxidation. Parabolic rate law of oxidation was obeyed by highly deformed sheet, but lightly rolled sheet required annealing before following same behavior. Influence of texture and deformation stresses is discussed. Interpretation of results is given (relation between internal stresses and chemical potential of copper.—INCO. 10860

6.3.6, 6.3.2, 6.3.8, 6.3.14

Methods of Corrosion Protection of Modern Anti-Friction Alloys. (In Russian.) B. V. Losikov. *Vestnik Mashinostroeniia,* **35,** No. 8, 58-60 (1955) Aug.

Corrosion process of copper, cadmium, lead and tin alloys; factors inducing corrosion; methods of protection. Tables. 9 references.—BTR. 10448

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37a

6.3.6

Impurities in Copper-Base Alloys. F. J. VERSAGI. *Foundry*, **83**, No. 12, 98-107 (1955) Dec.

Survey of the effects, detection and removal of impurities: information is taken from the literature (47 references) and from data supplied by nearly 100 U. S. foundries. Effect of fluxes; detection, effect and if necessary the removal of traces aluminum, antimony, iron, lead, nickel, phosphorous, manganese, silicon, sulfur, tin, zinc and various gases.—BNF. 11852

6.3.6

Rate of Solution of Copper in Solutions Containing Sulfuric Acid and Copper Sulfate Under Conditions of Constant Saturation of the Solution with Oxygen. A. I. KINEVSKII. *J. Applied Chem., USSR* (Zhur. Priklad. Khim.), **28**, No. 10, 1113-1116 (1955) Oct.

Above studied over wide range of concentrations used in manufacture of copper sulfate. Two tables, one figure, four references.—ATS. 11758

Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.

6.3.6, 3.7.2, 3.5.8

Effect of Zirconium and Titanium on Intercrystalline-Cracking Tendency of Beta-Brasses. E. C. W. PERRYMAN AND R. J. GOODWIN. *J. Inst. Metals*, **83**, Pt. 8, 378-382 (1955) April.

Sustained tensile stress and impact tensile tests in 3% sodium chloride were used to evaluate addition of small amounts of zirconium and titanium on beta brasses. Effects of other alloying additions. 11836

6.3.6, 3.7.2, 3.5.8

Intercrystalline Fracture of Beta-Brasses Containing Aluminum. E. C. W. PERRYMAN. *J. Inst. Metals*, **83**, Pt. 8, 369-377 (1955) April.

Intergranular failures occurring in binary and ternary beta brasses are discussed. Effects of aluminum may, in part, be exercised through some modification of grain boundary structure.—BL. 11764

6.3.6, 3.7.4, 3.5.8

Galvanic Potentials of Grains and Grain Boundaries in Copper Alloys. R. BAKISH AND W. D. ROBERTSON. *J. Electrochem. Soc.*, **103**, No. 6, 320-325 (1956) June.

Potentials of grains and grain boundaries were measured in pure copper, Cu_3Au and in alpha brass; the three cases represent the structural grain boundary in a pure metal, an alloy in which only one component is oxidized and an alloy in which both components are oxidized. Potentials were measured in ferric chloride and in aqueous ammonia, the former representnig an electrolyte in which only Cu_3Au is susceptible to stress cracking and the latter representing conditions in which brass is suscetpible to stress cracking. In general, it was found that the measured potentials could be correlated directly with observed structural changes and susceptibility to stress corrosion cracking. 11901

6.3.6, 3.8.4, 3.2.3, 3.4.6

Oxidation of Oxygen-Free High Conductivity Copper to Cu_2O. J. P. BAUR, D. W. BRIDGES AND W. M. FASSELL, JR. *J. Electrochem. Soc.*, **103**, No. 5, 273-281 (1956) May.

The effect of oxygen upon the oxidation behavior of OFHC copper was studied under conditions that assured that the involved system is copper/cuprous oxide/oxygen. Oxidation rate was correlated through use of two parallel reaction rates: a) a diffusion step (resulting in a pressure sensitive parabolic constant, K_p), and b) a phase boundary reaction (pressure insensitive). Application of the equation: $K_p = \text{const.}\ (P_{O_2})^{1/n}$ led to values for n: 950 C, n = 2.0; and 1000 C, n = 3.4. Theoretical considerations are outlined to emphasize that surface site saturation will lead to a cessation of the increase in K_p with increased oxygen pressure when the oxygen concentration and adsorption potential are sufficient to accommodate oxygen on all available sites. Photomicrographs of the growth of cupric oxide on cuprous oxide are included. 11903

6.3.8

The Electrochemical Behaviour of Lead: Corrosion, Cathodic Protection, and Passivation. J. VAN MUYLDER AND M. POURBAIX. Proc. 6th Meeting Internat. Cttee. Electrochem. Thermodynamics and Kinetics (Poitiers, 1954), 1955, 334-341.

An experimental study, by means of polarization curves, has been made of the effect of electrode potential and pH on the electrochemical behavior of lead in the presence of SO_4^{2-}, $C_2H_3O_2^-$, PO_4^{3-}, CO_3^{2-}, and OH^-, at pH 0-14. In $C_2H_3O_2^-$ or OH^- solutions, any oxidizing action causes corrosion; in SO_4^{2-}, CO_3^{2-}, or PO_4^{3-}, a slight oxidizing action causes corrosion, but a strong one protects by passivation.—MA. 11851

6.3.8, 3.8.2

Cathodic Corrosion and Protection of Lead. J. VAN MUYLDER AND M. POURBAIX. Proc. 6th Meeting Internat. Cttee. Electrochem. Thermodynamics and Kinetics (Poitiers, 1954), 1955, 342-349; disc., 349-350.

The behavior of strongly negatively polarized lead in the presence of unstirred and vigorously stirred solutions has been studied. With unstirred solutions of any composition, lead can corrode cathodically if its potential < 2.1 V. (against the normal hydrogen electrode); the final product of corrosion is lead in fine particles which detach from the cathode as a greyish-black cloud. Cathodic corrosion probably results from the transient formation of gaseous PbH_2, which decomposes rapidly into finely divided lead and hydrogen; its standard free energy of formation is calculated to be $+69.5 \pm 4.5$ kg.cal./g.-mol.; the standard electromotive force of the reaction, $Pb + 2H^+ + 2e \rightarrow PbH_2$, lies between -1.42 and -1.60 V. Although this work has shown that pure lead may sometimes be corroded if it is strongly polarized cathodically in aqueous solutions, these results should not be applied to the behavior of lead in soils.—MA. 11783

6.3.8

Absorption of Hydrogen by Lead and by Its Alloys with Magnesium and Calcium. (In German.) W. MANNCHEN AND M. BAUMANN. *Metall*, **9**, No. 15/16, 686-688 (1955) August.

In view of the improved properties of lead on addition of traces of tellurium, selenium, arsenic and lithium, which form hydrides, authors suspect that presence of hydrogen may be a contributory cause of the improvement. Present paper, an introductory one, describes investigations showing that hydrogen is not present in electrolytic or work lead (even after melting under hydrogen), or in lead-copper up to 1 percent copper (higher contents may lead to hydrogen absorption). Lead-magnesium alloys up to 17 percent magnesium show an increasing ability to absorb hydrogen, which authors connect with the phase Mg_2Pb.—BNF. 10884

6.3.8

Lead Reference Sheet. Part II. KEMPTON H. ROLL. Lead Industries Association. *Chem. Eng. Progress*, **51**, 104F (1955) Feb.

The corrosion characteristics of lead to a large number of acids, alkalies, their salts, gases and organic materials are tabulated. These corrosion resistance characteristics are reviewed in relation to the application of lead to a group of industrial processes.—NSA. 10558

6.3.9

Protection of Molybdenum at High Temperatures. L. F. YNTEMA. *J. Electrochem. Soc.*, **102**, No. 7, 172C-173C (1955) July.

Possible methods of protecting molybdenum components for use in jet engines are indicated: ceramic coatings, nickel cladding, silicide coatings, hot dipped aluminum-silicon coatings.—BNF. 11048

6.3.9, 3.8.4, 3.5.9

Kinetics and Mechanism of the Oxidation of Molybdenum. M. SIMNAD AND AIJA SPILNERS. *J. Metals* (Trans. AIME), **7**, No. 9, Section 2, 1011-1016 (1955) September.

The rates of formation of the different oxides on molybdenum in pure oxygen at 1 atm. pressure have beenn determined in the temperature range 500 to 770C. The rate of vaporization of MoO_3 is linear with time and the energy of activation for its vaporization is 53,000 cal per mol below 650C and 89,600 cal per mol at temperatures above 650C. The ratio $MoO_{3(\text{vaporizing})}/MoO_{3(\text{surface})}$ increases in a complicated manner with time and temperature. There is a maximum in the total rate of oxidation at 600C. At temperatures below 600C, an activation energy of 48,900 cal per mol for the formation of total MoO_3 on molybdenum has been evaluated. The suboxide MoO_2 does not increase beyond a very small critical thickness. At temperatures above 725C, catastrophic oxidation of an autocatalytic nature was encountered. Pronounced pitting of the metal was found to occur in the temperature range 550 to 650C. Marker movement experiments indicate that the oxides on molybdenum grow almost entirely by diffusion of oxygen anions. (auth).—NSA. 11007

6.3.9

The Tensile Properties of Molybdenum at Elevated Temperatures. J. W. PUGH. *Trans. Am. Soc. Metals*, **47**, 984-1001 (1955).

Short-time constant-rate tensile and long-time creep tests were carried out on as-swaged and recrystallized molybdenum (0.05 carbon, 0.003 oxygen, 0.001 nitrogen, 0.003 percent hydrogen) from room temperature to 1140C; results indicate that a strengthening phenomena depending on temperature and strain, such as strain ageing, is responsible for its excellent strength properties at high temperatures.—BNF. 10629

6.3.9, 3.7.3

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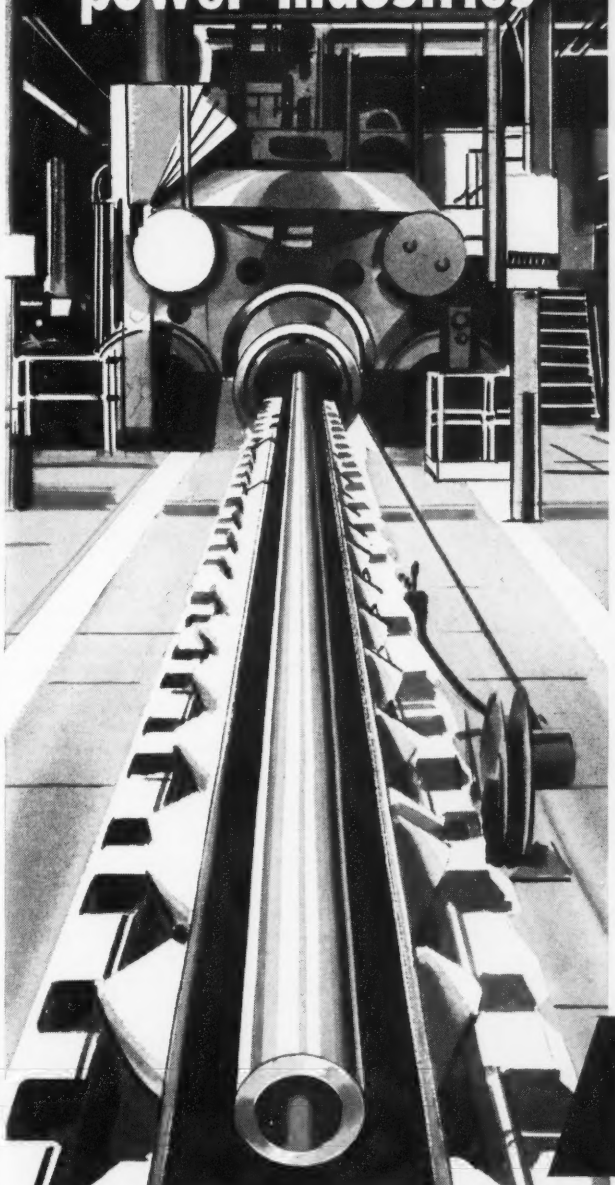

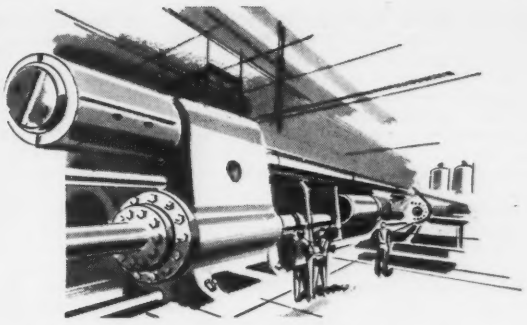

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How to Work Arc-Cast Molybdenum, *Iron Age,* **176,** Nos. 5, 6, 79-81, 95-97 (1955) August 4, August 11.

Part I, Arc-cast molybdenum, molybdenum-0.3 niobium, molybdenum-0.5 titanium, molybdenum-1 vanadium and molybdenum-2 tungsten are produced commercially in ingots up to 9 inches in diameter. Properties of arc-cast and powder metallurgy molybdenum are compared; high temperature and mechanical properties of molybdenum; corrosion resistance. Part II. Hot working, drawing, spinning, machining, cutting, grinding, welding and brazing of molybdenum and alloys.—BNF. 10799

6.3.10, 3.8.2, 5.3.4

Electrochemical Behavior of Nickel. Voltage-pH Equilibrium Diagram of the Nickel-Water System at 25C. Corrosion of Nickel; Nickel Plating; Nickel Storage Batteries. (In French.) E. Deltombe, N. de Zoubov and M. Pourbaix. Centre Belge d'Etude de la Corrosion, Rapport Technique, No. 23, June, 1955, 28 pp. Available from Centre Belge d'Etude de la Corrosion, 21 rue des Drapiers, Brussels, Belgium.

Study of electrochemical behavior of nickel by means of a voltage-pH equilibrium diagram. Conclusions are drawn relative to corrosion, general properties of nickel and its oxides, electrochemical and chemical deposition and to the functioning of nickel alkaline storage batteries. Tables, diagrams. 61 references. —BTR. 10529

6.3.10, 8.8.1

Alloys in Your Plant Can Give You Product Purity, Physical Strength, Corrosion Protection, Erosion Resistance. R. L. Davidson. *Petroleum Processing,* **10,** No. 9, 1393-1395 (1955) Sept.

Use of nickel and high nickel alloys to combat specific corrosion, erosion, and purity problems in petrochemical processes. Included are Incoloy, Inconel and 310 stainless furnace tubes in ethylene pyrolysis and synthetic gas manufacture; pure nickel vessels and Duranickel extrusion dies in PVC manufacture; nickel, nickel-cladding and nickel-plating in polyethylene manufacture and phenol handling; nickel domes to collect chlorine in sodium chloride electrolysis, as well as Monel linings, stainless steel and Monel tanks in tetraethyl lead manufacture; Monel, Hastelloy and stainless steel in production of synthetic detergents; and Inconel mixing jets, nickel piping, and Monel centrifuges in synthetic glycerine manufacture. (From interview with Inco technical staff members.)—INCO. 10737

6.3.10, 3.2.3

Oxide Scaling on Nickel. (In Polish.) Lucjan Czerski and Franciszek Franik. *Archiwum Gornictwa i Hutnictwa,* **3,** No. 1, 43-68 (1955).

Mechanism of scale formation at high temperatures; chemical composition and micro-structure of scale at various depths. Experimental method involves use of a "witness" metal (platinum wires) in following the scaling process. Diagrams, micrographs, tables. 24 references.—BTR. 11928

6.3.10, 3.7.3

The Heating of Nickel. Brochure, 1955, 47 pp. Mond Nickel Co. Ltd., Thames House, Millbank, London, S.W.1.

Indicates how intergranular attack by sulfur and oxygen on heated nickel takes place and how nickel surfaces can be contaminated with sulfur before or during heating. Precautions to be observed in heating for hot forming, annealing, or welding are emphasized; thus oil, fingerprints, etc., must first be removed by some cleaning procedure. Examples of chemical plant made in nickel or nickel-clad steel are given.—BNF. 11904

6.3.11, 6.3.6, 5.8.2

Chlorophyll Keeps Silver and Copper Bright. Department of Scientific and Industrial Research. Typescript, February 9, 1955, 1 p. Available from DSIR, 15 Regent Street, London, S W. 1.

It has been found at the Chemical Research Laboratory, Teddington, that wrapped silver and copper and their alloys remain untarnished in atmospheres containing a high proportion of hydrogen sulfide if their wrappings are impregnated with chlorophyll. In the case of atmospheric hydrogen sulfide, it is sufficient if the metals are laid on chlorophyll paper, tarnish being prevented for some time. Chlorophyll (the green coloring matter of plants) absorbs hydrogen sulfide.—BNF. 10533

6.3.15, 1.6

Physical Metallurgy and Heat Treatment of Titanium Alloys. Richard J. McClintick, G. William Bauer and Lee S. Busch. Book, 1955, 60 pp. Available from: Mallory-Sharon Titanium Corp., Niles, Ohio.

This monograph relates to the characteristics of titanium and titanium alloys produced by the vacuum double melting Method S which assures alloy segregation and permits holding carbon and gaseous contaminants to very low limits. Five grades are considered. Data

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Oil and Gas Journal 54 No. 29, 135 (1955)
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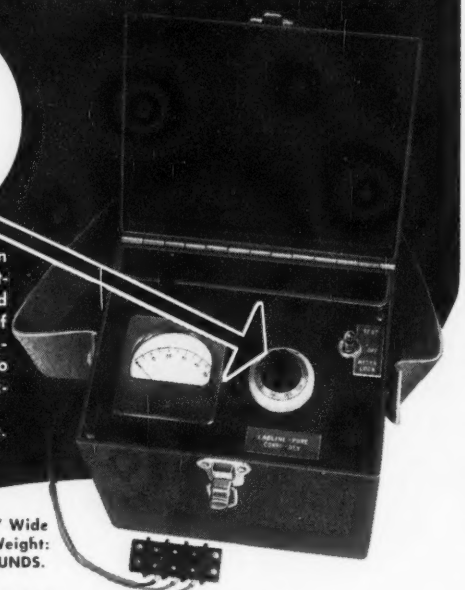
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INDEX TO ADVERTISERS

Vol. 13 February, 1957 No. 2

	Page
Aluminum Company of America	106, 107
Amercoat Corporation	Inside Front Cover
American Chemical Paint Co.	109
American Cynanamid Company	115
American Hot Dip Galvanizers Association, Inc.	10
Byers, A. M. Company	131
Carboline Company	104
Cathodic Protection Service	105
Cherokee Laboratories, Inc.	9
Claymont Steel Products of Wickwire Spencer Steel Division The Colorado Fuel and Iron Corp.	12, 13
Copon Associates	93
Corrosion Engineering Directory	94
Corrosion Services, Inc.	92
Curtiss-Wright Corporation	141
Dearborn Chemical Company	103
DeVilbiss Company, The	1
Diamond Alkali Company	85
Dow Chemical Company	2, 144
Dowell, Inc.	83
Dresser Manufacturing Division, Dresser Industries, Inc.	14
Duriron Company, The	Inside Back Cover
Erico Products Company	5
Federated Metals Division, American Smelting & Refining Co.	89
Fibercast Corporation, Division of Youngstown Sheet & Tube Co.	102
Good-All Electric Manufacturing Co.	108
Haynes Stellite Company, Division of Union Carbide & Carbon Corp.	15
Humble Oil & Refining Company	119
Inertol Company, The	98
International Nickel Company, Inc., The	117
International Paint Company, Inc.	133
Johns-Manville Sales Corporation	96
Koppers Company	135
Labline, Inc.	142
Long, David E., Corporation	110
Lukens Steel Company	111
Maloney, F. H. Company	95
Mavor-Kelly Company	125
Mayes Brothers, Inc.	82
Metal & Thermit Corporation	137
Midwestern Pipe Line Products Co.	108
Minnesota Mining & Manufacturing Co.	139
Mutual Chemical Division, Allied Chemical & Dye Corporation	81
National Carbon Co., Division of Union Carbide & Carbon Corporation	99
Pittsburgh Coke and Chemical Co.	Back Cover
Polyken Products, Dept. of the Kendall Company	86
Positions Wanted and Available	84
Ruberboid Company	90
Rust-Sele Company	123
Shawinigan Resins Corporation	113
Smith, Nowery J.	134
Spee-Flo Corporation	129
Standard Magnesium Corporation	120
Stewart Brothers, Division of Instrument Laboratories	110
Tapecoat Company, The	102
Thornhill-Craver Company	101
Tretolite Company	11
Tropical Paint Company	128
Truscon Laboratories Division of Devoe & Raynolds Co., Inc.	127
U. S. Industrial Chemicals Co., Division of National Distillers Products Corporation	7
United States Stoneware Company	91
Wholesale Coke Company	88
Wilbur & Williams Company	143
Williamson, T. D., Inc.	80
Wright Chemical Corporation	132

presented are based on an investigation carried out under a Navy contract.

The introduction covers nomenclature of phases, classification, interstitial impurities and other matters. The second part pertains to hardening theories while the third covers annealing. Hardening data include discussions relating to alpha alloys, martensitic type alloys and metastable beta alloys.

Forty-two references and a subject index are included. 11819

6.3.15, 3.5.9

How Titanium Alloys Behave at High Temperatures. D. R. Luster and B. L. Shakely. *Iron Age*, **175,** No. 12, 96-99 (1955) March 24.

Tests by Rem-Cru Titanium, Inc. to determine behavior of titanium at temperatures up to 1000 F. Effects of alloying elements are given. Discussion of notch sensitivity characteristics, fatigue properties and effect of various strain rates and temperatures on observed strength of titanium alloys included.—BL. 11880

6.3.16, 3.5.7, 3.5.9, 3.8.4

High Pressure Oxidation of Metals—Tungsten in Oxygen. J. P. Baur, D. W. Bridges and W. M. Fassell, Jr. *J. Electrochem. Soc.*, **103,** No. 5, 266-272 (1956) May.

Tungsten rod and sheet were found to oxidize linearly in oxygen from 600 to 850 C at oxygen pressures ranging from 20 to 500 psia. Oxidation rate increased with increased oxygen pressure at temperatures 750-850 C. Theoretical considerations indicate that an equilibrium adsorption process occurs prior to the rate-determining step. The assumption of a linear change of adsorption energy with increase of surface coverage allowed observed oxidation rates to be corrected for pressure effect. The activation energy was 48 kcal. Tungsten sheet volatilization losses were appreciable above 800 C. Only tungsten rod data were free from volatilization losses at 850 C. Photographs are included showing the effect of shearing samples at room temperature prior to oxidation on the final physical appearance of the oxide. Cold shearing produces exfoliated tungsten oxide. 11795

6.4 Non-Ferrous Metals and Alloys—Light

6.4.1, 2.5, 1.6

ASTM Standards on Light Metals and Alloys. Book, December, 1955, 276 pp. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Numerous specifications are given on aluminum and aluminum-base alloys, including ingots, castings, bars, rods, wire and shapes, forgings, pipe and tubes, sheet and plate, wrought products for electrical purposes, filler metal, electroplating; magnesium and magnesium-base alloys, including ingots, castings, bars, rods and shapes, forgings, sheet, tubes.

Tentative methods of tension testing of metallic materials and standard methods of sampling wrought non-ferrous metals and alloys for determination of chemical composition are included. 11685

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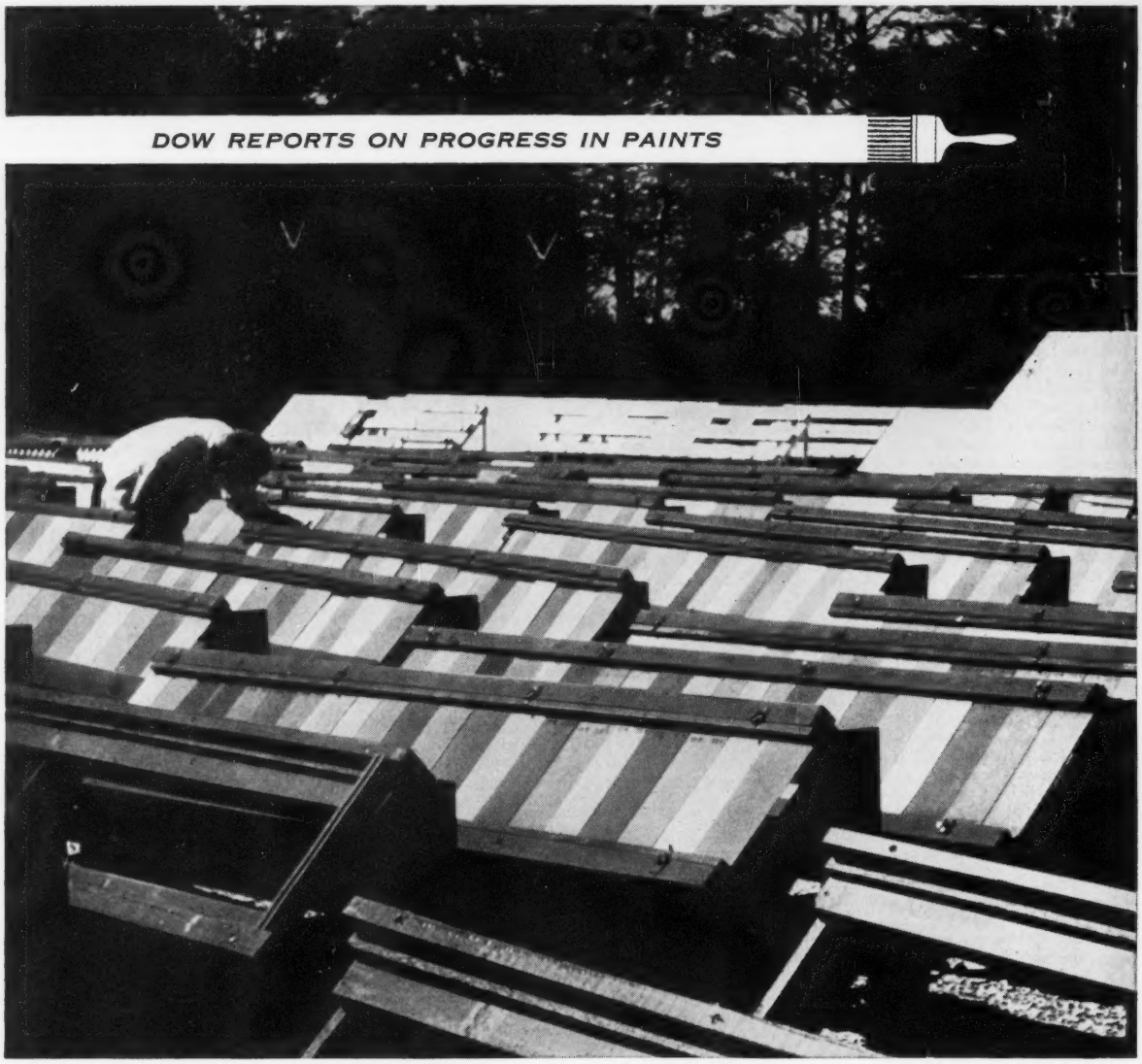

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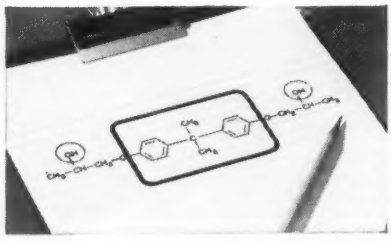

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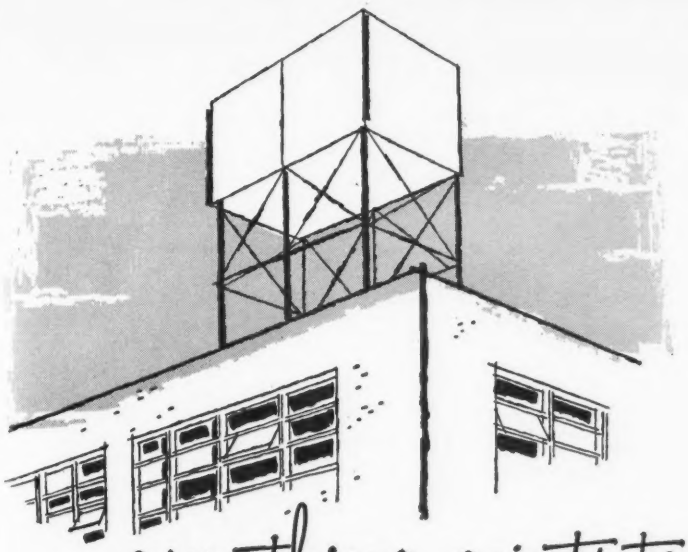

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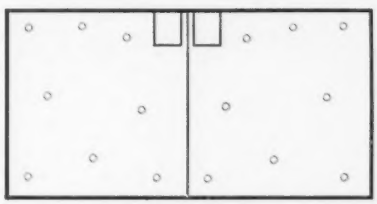

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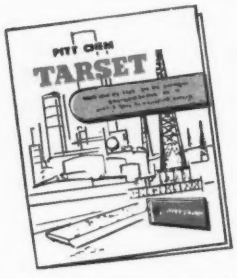

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